Initial validation of the Arthroscopic Skills Acquisition Tools (ASATs): A low cost, online tool to develop and evaluate core skills for shoulder arthroscopy

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Glossary of Terms

2D: 2-Dimensional

3D: 3-Dimensional

AO: Arbeitsgemeinschaft für Osteosynthesefragen

ASATs: Arthroscopic Skills Acquisition Tools

BOA: British Orthopaedic Association

CCT: Certificate of Completion of Training

GRS: Global Rating Scale

JCST: Joint Committee of Surgical Training

MIS: Minimally Invasive Surgery

NHS: National Health Service

OR: Operating Room

UK: United Kingdom

USA: United States of America

VR: Virtual Reality

Dedication

This work would not have been possible without the commitment of my family.

To my wife, Praksha: you have stayed by my side, from application to the MPhil programme, sacrificing weekends for me to collect data to proof-reading my final thesis. You have been with me through the frustrations of trying to disseminate the findings of this work and kept me on track of thinking of the bigger picture. Thank you.

To my children, Kaisha, Preesh and Krish: you have always kept my work in perspective. When things are hard, then I only need to look at your smiles to keep me going. Preesh – your period of illness inspired me into being strong through times of adversity. Thank you all.

To my parents, Mum and Dad: you have always encouraged me in all my endeavours and let me think "outside the box" which has allowed me to have these ideas in the first place. Thank you both.

To the superior force which oversees Karma: I hope I have done some good. Thank you for this opportunity.

To all those well-wishers from colleagues to friends: Thank you for your understanding, time and support throughout this whole process.

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I also thank Mr. Michael Anderton, an orthopaedic registrar in the North West Deanery, for help in data collection during some assessment sessions.

I wish to thank staff from the Bridgewater Hospital (Manchester) for access to the virtual reality simulator, the University of Manchester and the Scalpel Surgical Society with their help in recruiting participants.

Declaration

I declare that I have solely written this thesis, and that the content and findings of the studies are not being submitted for the award of any other higher degrees, except for the award of an MPhil at the University of Salford.

I declare that I have disseminated the results of the study at recognised national and international research meetings as podium and poster presentations as listed below.

Podium Presentations:

- 50th Golden Anniversary Congress of the European Society for Surgical Research (ESSR), Liverpool, England. September 2014.

  This resulted in a published abstract. Full reference:

  Gandhi MJ, Anderton MJ, Funk L. Arthroscopic Skills Acquisition Tools (ASATs): an online simulator to develop core skills for arthroscopy. European Surgical Research. 2015; 55 (suppl 1): 1-167.
- 25th SECEC-ESSSE (European Society for Surgery of the Shoulder and Elbow) Congress, Istanbul, Turkey. September 2014.

  This resulted in a published abstract. Full reference:

  Gandhi MJ, Anderton MJ, Funk L. Can a low fidelity simulator teach the same core arthroscopic skills as a high fidelity simulator? International Journal of Surgery 12 (2014), S83.

Poster Presentations:

- 26th SECEC-ESSSE (European Society for Surgery of the Shoulder and Elbow) Congress, Milan, Italy. September 2015.
- British Orthopaedic Association (BOA) Annual Congress, Liverpool, England. September 2015.

A manuscript has also been published in a peer-reviewed journal targeting an international audience for arthroscopy. The full reference is:

Gandhi MJ, Anderton MJ, Funk L. Arthroscopic Skills Acquisition Tools (ASATs): an online simulator to develop core skills for arthroscopy. Arthroscopy: The journal of arthroscopic and related surgery. 2015; 31(9):1671-1679.

I declare that I have received the following prizes relating to this work:

- British Orthopaedic Association (BOA): Runner-up Award in “Innovation in Simulation and Technology Enhanced Learning” at BOA Annual Congress, Brighton, England. September 2014.

I declare that I have been shortlisted for the following prizes relating to this work:

- Shortlisted for Best Poster Prize at the 25th SECEC-ESSSE (European Society for Surgery of the Shoulder and Elbow) Congress, Istanbul Convention and Exhibition Centre, Istanbul, Turkey. September 2014.

Abstract

There are increasing time pressures on surgical training, including the European Working Time Directive. Developing arthroscopic surgical skills (keyhole surgery into a joint) has a longer learning curve than open surgery, driving the need to develop efficient training techniques. Virtual reality (VR) simulators offer great potential but such high fidelity simulators are not widespread because of their cost and subsequent access restrictions.

A structured program of developing transferrable skills using widely accessible, low cost, but low fidelity simulators may help maximise training opportunities on VR simulators. To address this, the author developed the Arthroscopic Skills Acquisition Tools (ASATs), designed to develop and evaluate the core skills for shoulder arthroscopy, to complement training on VR simulators, cadavers and real patients.

This thesis presents the initial validation study of the ASATs. Performance, assessed using a VR simulator correlates with intra-operative and cadaveric arthroscopic performance and can differentiate between novices and experts, thereby providing a practical "gold standard" test environment for the initial validation of the ASATs. This MPhil study aims to evaluate correlations between performance measured using one of the ASATs and performance on a VR shoulder arthroscopy simulator.

Following ethical approvals, 49 volunteers were recruited and individually received a 1-hour standardised introduction and familiarisation process containing written material, videos and five different ASATs. They were then assessed using a sixth ASAT and four VR tasks. Correlations were assessed between the ASAT measures and the VR measures using Pearson's correlation coefficients.

The results showed 64 significant correlations from a possible 171, of which 19 showed a moderate or stronger relationship ($r > 0.5$). More significantly was the correlations pattern, which helps to identify which performance measures to target during further development work on the ASATs. However, there remains questions about the optimal timing, intensity and competence levels of such training.

Chapter 1 – Introduction to the thesis and study

The student (MJG) is a practicing doctor who is in his final year of training (10th tier post-graduation from medical school) in an orthopaedic training programme in the United Kingdom (UK). He is aspiring to be a shoulder surgeon, and has a particular interest in arthroscopic surgery. He has experienced first-hand many of the different training methods described and this has inspired him to develop a low cost simulation system, the initial validation of which is the focus of this thesis.

The General Medical Council (GMC) states as part of "Good Medical Practice", a doctor must[1]:

"… be competent in all aspects of work…"

"…keep skills up to date…"

"…regularly take part in activities that maintain and develop competence and performance…"

Being competent, keeping skills up to date and maintaining performance is not just in the interest of the individual surgeon, but also important to other stake holders such as hospitals and patients.

Traditional surgical training has been delivered on a one-to-one basis, similar to a master-apprentice relationship.[2] This method of surgical training is evolving to address the main modern-day challenges:

1. Minimising patient harm and associated litigation[3–7].
2. Consensus for the need to be able to objectively define surgical performance[4,8–15]
3. Standardising training and improving training efficiency[15–18].
4. Improving hospital efficiencies[3,19].
5. Responding to enforced working time [2,10,20–28].

Simulation can address the points raised above, but as will be addressed, practical limitations currently exist with implementation[29]. Specifically, high fidelity simulation systems may allow the development of skills but the practical application of such systems has been called into question due to poor availability. This has led to the development of low fidelity systems, with high accessibility. One such simulator was designed by the student (MJG) to specifically address these limitations. This simulator was named the Arthroscopic Skills Acquisitions Tools, or ASATs for short.

The thesis begins with a literature review and Chapter 2 summarises how this search was performed. An overview of arthroscopy, arthroscopic skills, current training methods and methods of skills assessment is presented.

This leads onto the drivers for new training methods and overview of simulation as a possible solution. The evidence is reviewed and the practical pressures that are limiting the uptake of simulation is highlighted. This brings the thesis onto why there is the need for a new solution like the ASATs and defines this thesis aims.

Chapter 3 presents the methodology to answer the study question highlighted in the thesis aims. This includes the details of the necessary ethics and recruitment of participants. Chapter 4 presents the findings and interpretation of the results. Chapter 5 is a discussion aiming to contextualise the results, and how these findings fit into the current evidence. This helps clarify what new has been learned and how to guide further research in this field.

Chapter 2: Literature Review

Aim of the Literature Search

A review of the published literature was conducted to establish the full journey of a training doctor wishing to become an orthopaedic surgeon and the opportunities available to develop surgical skills, specifically arthroscopic skills. Such opportunities can come from training in other surgical specialties that employ minimal invasive surgery (MIS) and from within orthopaedics.

The first step was to identify the skills required for arthroscopy. Traditional and current training methods to acquire these skills are reviewed. This was followed by identifying methods to assess arthroscopic skills. A review is presented of the attempts to develop tools that aim specifically to improve surgical skills. The drivers for new training methods were explored and the concept of simulation introduced.

A comprehensive review of the different types of validation studies for arthroscopic simulators performed is presented. The end of this section highlights the practical pressures limiting uptake of simulation and introduces the Arthroscopic Skills Acquisition Tools.

Finally, the gap in the literature is identified, which this thesis aims to address.

Search Terms

Virtual Reality
Arthroscopy
Laparoscopy
Orthopaedics
Orthopedics
Simulation
Computer Simulation
Simulator
Learning Curve
Operating room
Operating table

Databases Search

MEDLINE (from 2004-2016).

Excerpta Medica dataBASE (EMBASE) (from 2004-2016).

Google Scholar website.

An overview of arthroscopy

Arthroscopy is a form of minimal invasive surgery (MIS) or key-hole surgery into a joint. Other forms of MIS include laparoscopy, where the instruments and camera are placed into different parts of the body, typically the abdomen. Arthroscopy is carried out by surgeons in the field of Orthopaedics, whilst laparoscopy can be performed by surgeons in the field of General Surgery or Gynaecology.

Arthroscopy can be used in diagnosis and treatment of an increasing number of joint conditions[30]. In addition to smaller scars, benefits of arthroscopic surgery can include shorter recovery time, reduced risk of infection and shorter hospital in-patient stay.

It is accepted that arthroscopy requires a different type of skill set to open surgery[31]. Core skills training for the next generation of orthopaedic surgeons needs to include arthroscopic skills[19,32–34].

Arthroscopic Skills

Skills required to perform minimally invasive surgery (MIS) and arthroscopy

As indicated by the lack of a consensus on assessment, discussed in the section "Current methods of arthroscopic skills assessment", there remains some debate on what constitutes the core hand-eye coordination skills that needs to be attained over the course of training to be an arthroscopy surgeon[15,19,35,36].

Arthroscopic surgery requires many of the same technical skills required for other minimal-invasive surgical procedures. They all utilise a camera and instruments through separate access portals. In both MIS and arthroscopy, it is accepted that hand-eye coordination and manual dexterity[37] are the core skills. Hand-eye coordination requires the appreciation of inverted hand-eye movements. This is because the body acts as a fulcrum (Figure 1). This represents a Class 1 lever and this is drawn schematically in Figure 2.

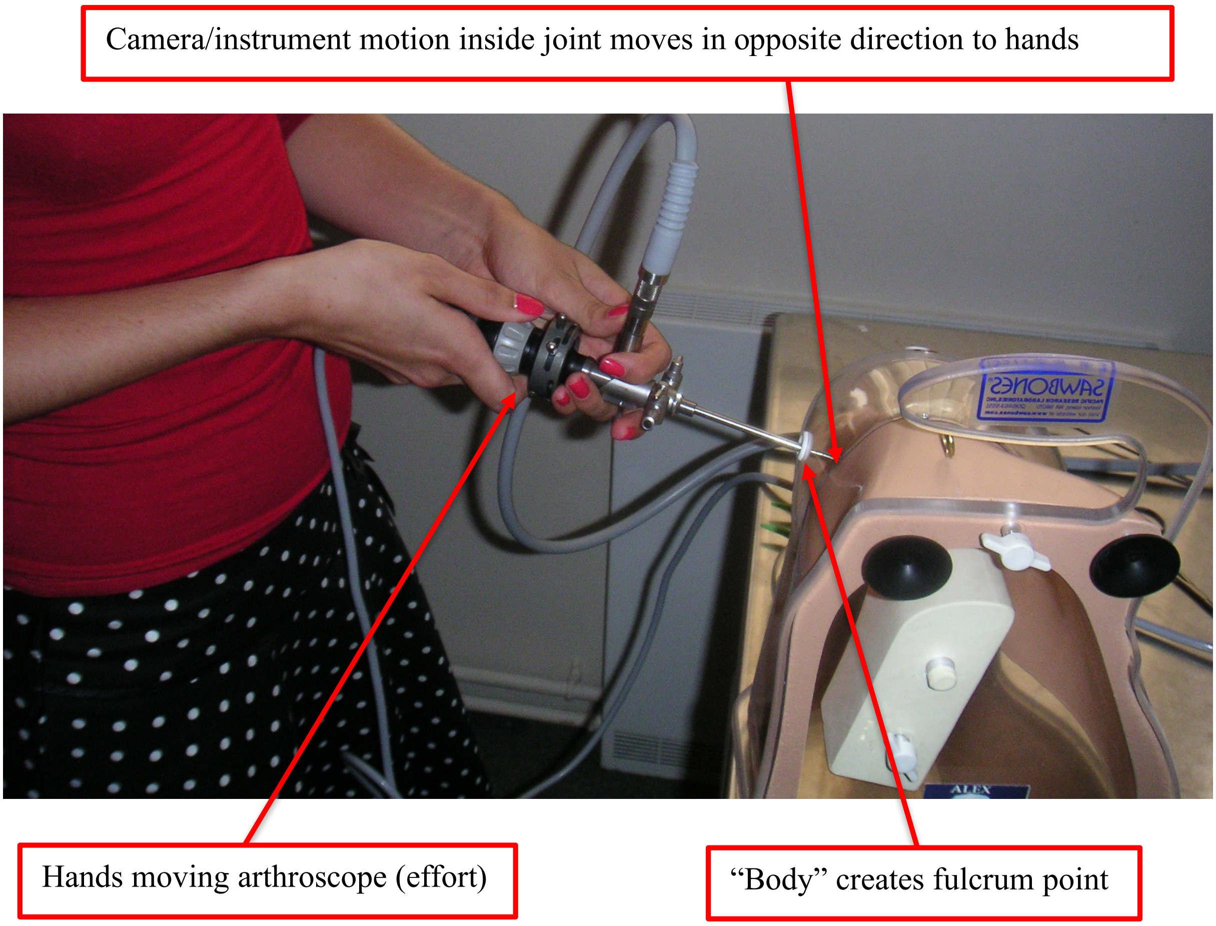

Figure 1: Shoulder scope (on a plastic shoulder model) showing the hand position, fulcrum point and instrument within the joint.

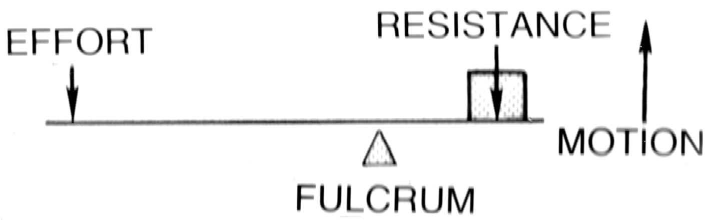

Figure 2: Schematic diagram of a Class 1 Lever highlighting the resultant opposite direction of camera/instrument motion to hand movement (effort).

The operator's visual field usually is not wide enough to contain their hands and the camera display monitor because they are positioned at a distance from each other. This means the operator can either look at their hands or the monitor. This results in the disconnection of visual and proprioceptive stimuli. This presents unique technical challenges, namely, the simultaneous interpretation of proprioceptive and visual stimuli from a three-dimensional structure presented as a two-dimensional image and hence development of competence in triangulation is also a central skill[31,38].

The additional skills described in the literature include reaction speed, anticipation, steady and accurate movements, and ability to reverse hand-eye coordination[32,35,39,40]. In arthroscopy, the primary surgeon often uses one hand for camera manipulation allowing the other hand to be used for instrument manipulation.

It is traditional thinking that these skills are best acquired through actual instrument handling and rely on realistic substitutes for live patients[38].

How arthroscopy is different from other forms of minimally invasive surgery

There are some notable differences in surgical technique between laparoscopy and arthroscopy[37,41].

In laparoscopy, the primary surgeon uses both hands for manipulation of the instruments, and an assistant to hold the camera to visualise the operative field. In arthroscopy, the primary surgeon often uses one hand for camera manipulation allowing the other hand to be used for instrument manipulation. In arthroscopy, the operating field is more confined, as joints are smaller than the abdomen, thus meaning the instruments used are shorter. The structures within a joint during arthroscopy also provides more tactile feedback, as cartilage and bone are firmer surfaces than abdominal structures[37].

Finally, in laparoscopy the operative field is expanded using carbon dioxide gas (CO_2) whilst in arthroscopy it is inflated using irrigation fluid[42]. The effect of the fluid is that it produces a flow effect away from the camera, pushing structures of interest away from visualisation. Techniques need to be employed to try and counter this effect. These are a different set of skills that are not developed during laparoscopic training.

How shoulder arthroscopy is different from other forms of arthroscopy

Arthroscopy is being performed in multiple joints, including shoulder, elbow, wrist, hip, knee and ankle. The two most commonly performed arthroscopies are in the shoulder and knee joint. Not all arthroscopies utilise the same skills as is evident between shoulder and knee arthroscopy[41,43].

In the shoulder joint, the major plane of movement is vertical, the operating field is smaller, and the primary surgeon's hands are either perpendicular to each other (Figure 3) or facing each other (Figure 4)[44]. In the knee joint, the major plane of movement is horizontal, the operating field slightly larger and the surgeon's hand primarily parallel to each other[44]. The effect of the hand position tests the surgeon's ability to triangulate.

In shoulder arthroscopy, the patient can be positioned either in the beach chair position (Figure 5) or in lateral decubitus (Figure 6). This latter position turns the patient's anatomy through 90 degrees and tests the surgeon's ability to navigate the gleno-humeral joint effectively. In knee arthroscopy, the patient is positioned supine and the leg manipulated to allow better visualisation (Figure 7), and that may include part of the operation with the leg in a "figure-of-4" position (Figure 8). This again turns the patient's anatomy through 90 degrees.

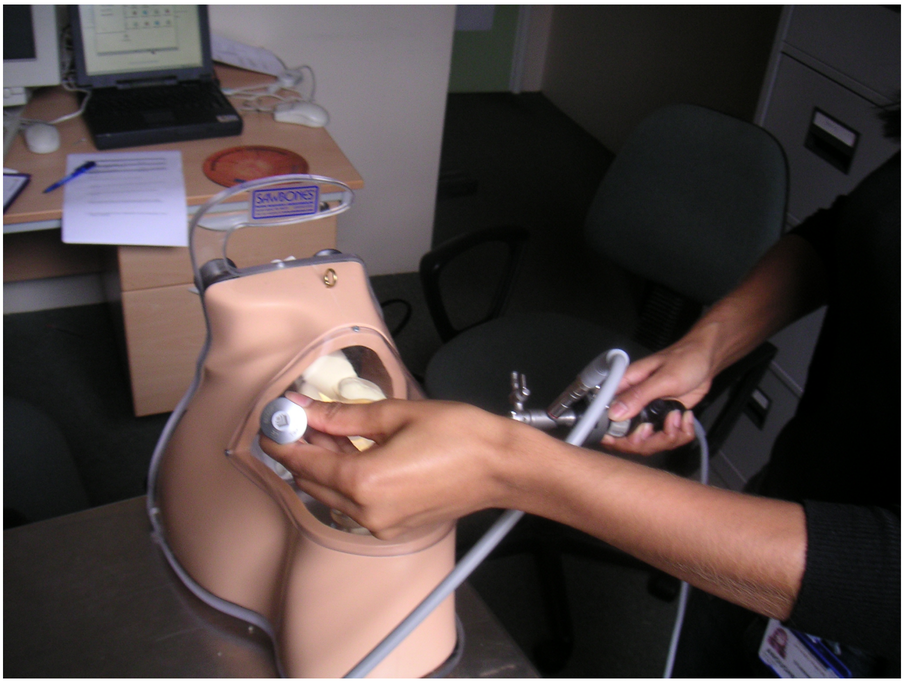

Figure 3a: (above) Shoulder scope (on a plastic shoulder model) hand position showing the camera and instrument perpendicular to each other.

Figure 3b: (below) Position of the camera and instrument perpendicular to each other.

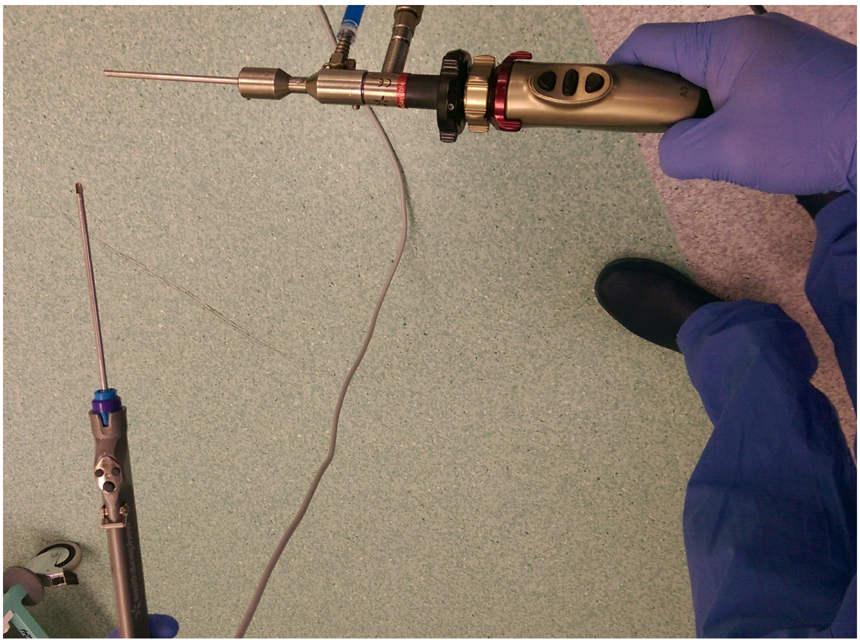

Figure 4a: (above) Shoulder scope (on a virtual reality shoulder model) hand position showing the camera and instrument opposite to each other.

Figure 4b: (below) Position of the camera and instrument perpendicular to each other.

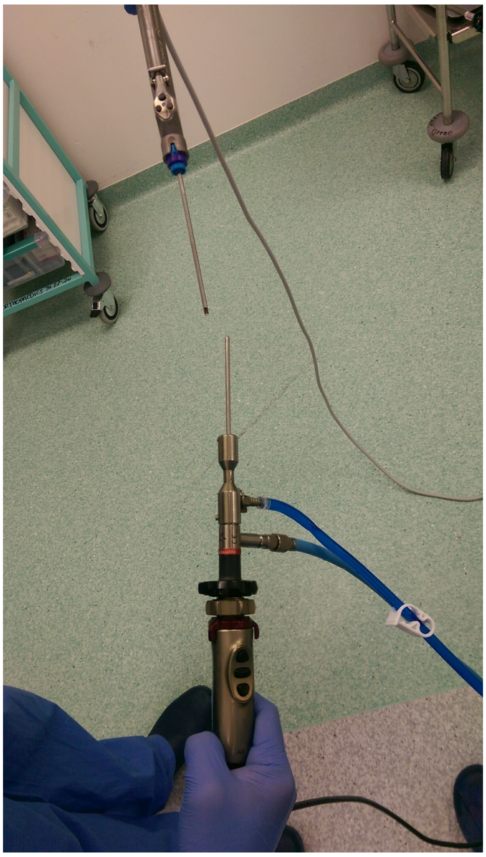

Figure 5: Shoulder arthroscopy in the beach chair position showing the joint line (red) being perpendicular to the floor (yellow) (image courtesy of Len Funk, www.shoulderdoc.co.uk).

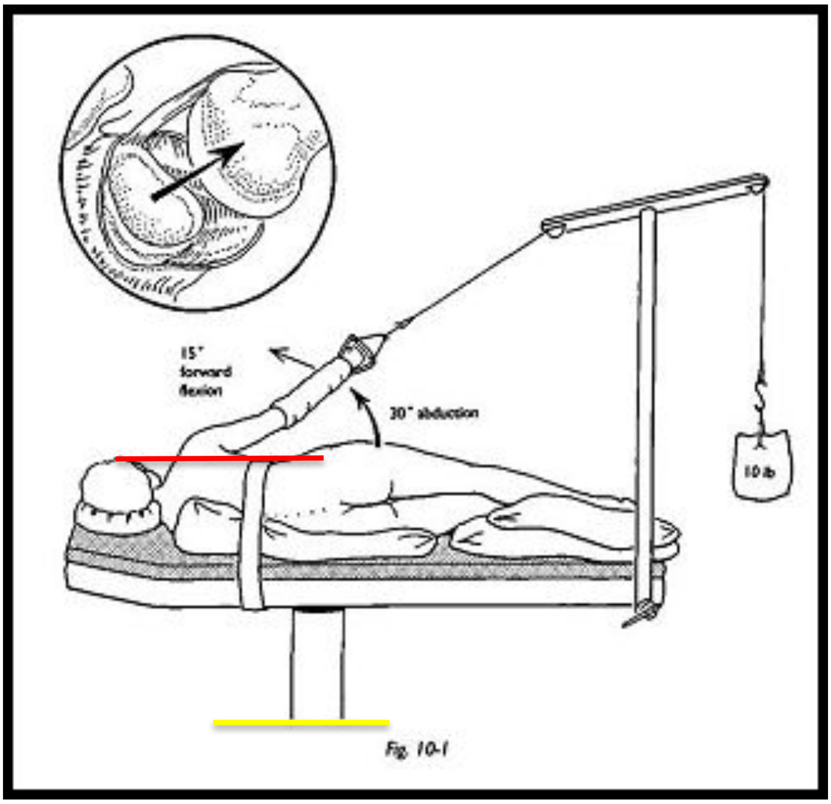

Figure 6: Shoulder arthroscopy in the lateral decubitus position showing the joint line (red) being parallel to the floor (yellow) (image courtesy of Len Funk, www.shoulderdoc.co.uk).

Figure 7: Knee held in a flexed position whilst supine showing the joint line (red) being parallel to the floor (yellow).

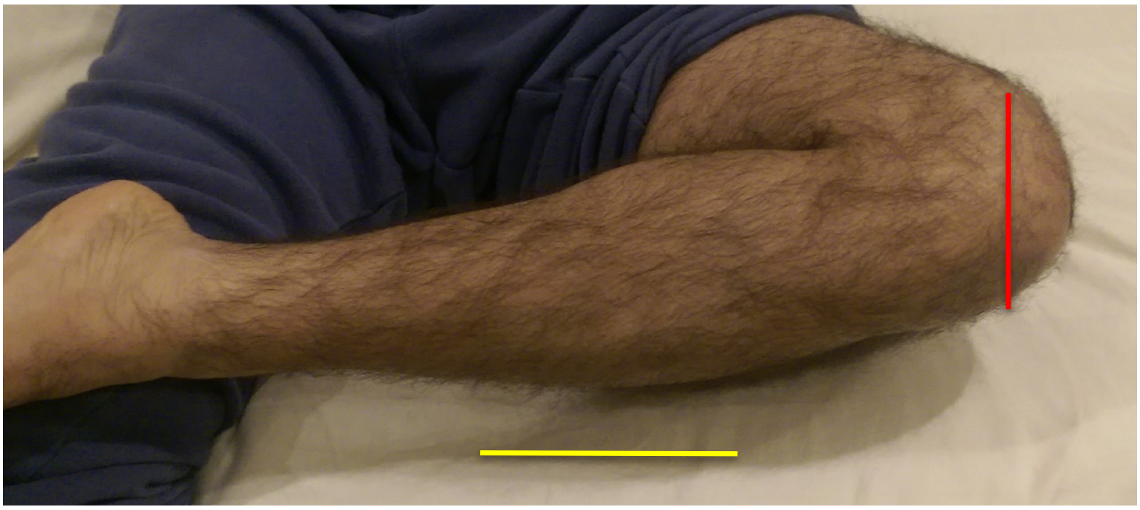

Figure 8: Knee held in a “figure of 4” position whilst supine showing the joint line (red) being perpendicular to the floor (yellow).

Learning Curves of minimally invasive surgical skills and arthroscopy

The development of any skill is associated with a learning curve[43,45]. If plotted with time spent practicing (experience) along the x axis, and a performance measure (learning) on the y-axis, this learning curve typically reaches a plateau (Figure 9). The variables that may influence the final look of this curve include the difficulty of the skill being acquired, the individual's ability to acquire the skills and other confounding variables such as supplementary training and intensity of training opportunities[46–48].

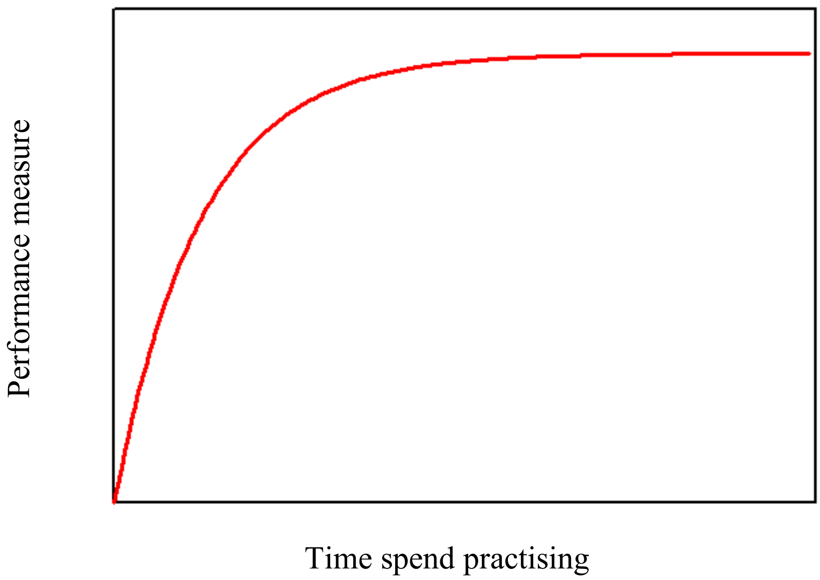

Figure 9: Learning curve graph. Image modified under the Creative Commons Attribution-Share Alike 3.0 Unported License. Original image ©Alan Fletcher 2013.

It has been shown that surgeons in the early phase of their arthroscopic skills learning curve have an increased risk of iatrogenic injury[6,10,49]. This is because these trainees often have problems with adequate joint visualisation and triangulation[50].

No predictive factors that represent a faster progression along a learning curve have been identified[51]. Practice through repetition can show progression through a learning curve, and even skill retention[45,51]. The transfer of these skills into theatre will be reviewed later ("Predictive/transfer validity evidence").

Traditional teaching in open surgery relies initially on observational training[38] but this has been shown to be sub-optimal in the development of MIS skills[49]. As a result, to acquire these skills and progress up the learning curve, specific training is required that includes many hours of practice[31,37] and a significant financial burden (in theatre)[4].

The amount of time spent practicing can be reduced by external factors such as Working Time Directives, which is reviewed later ("Drivers for new training methods"). This could slow the trainee reaching the plateau part of their learning curve. The impact of a slow learning curve increases the overall cost of training by increasing the time required for achieving competence. A slower learning curve also subjects patients to increased risk through iatrogenic injury. The effect it has on the trainees include decreasing confidence within the surgical procedure which may subsequently affect performance[3].

There have been studies published in the literature which look into progressing trainees along their learning curve, particularly in a simulated environment[37,46–48,51]. This has the advantages that there are no pressures associated with operating on real patients, and the focus on skills developments occurs in a controlled safe environment[15,52].

There is also evidence of a skills decay curve, defined by the loss of newly acquired skills if not practiced regularly[43]. It has been suggested that for advanced arthroscopic techniques, this skills decay occurs over 6 months after which the arthroscopic skills plateaus to baseline performance[43].

Current Training Methods

Training has multiple objectives and these can be targeted through different routes[20]. Broadly, surgical training can be split into knowledge acquisition and skills acquisition. Other objectives, such as decision-making, leadership and communication skills are also required[20,37], but these are not covered in this thesis.

Knowledge acquisition, such as anatomy, needs to be learned to be able to perform safe and effective operations. This is typically learned at a basic level at medical school and more detailed knowledge is developed during post-graduate training. As the anatomical knowledge of the surgeon is not the focus for this thesis, no further discussion is provided here.

Orthopaedic training requires a lengthy period of skills assimilation to develop established surgical techniques alongside rapidly evolving techniques[53]. Traditionally, skills have been developed during the actual procedure, for example during the operation (intra-operative skills acquisition)[38]. This often is accompanied by pre-procedure cognitive simulation and post-procedure feedback. Cognitive simulation can be as simple as checking the trainee knows the steps of the surgical procedure to virtual operative experience on a mobile device[54]. Post-procedure feedback has traditionally been sub-optimal, with little in the way of constructive feedback. As a result, more objective feedback mechanisms and tools have been developed and these will be reviewed in the "Methods of arthroscopic skills assessment" section of the thesis.

More recently, skills simulation has progressed to allow reproduction of the surgical steps of specific operations[53]. Surgical approaches on human cadavers has been the gold standard in surgical training[55].

Clearly there is tissue variability and ethical considerations when using human cadavers or animal models, so there have been attempts to simulate using different models. Simulating open orthopaedic surgical techniques using synthetic bone substitutes has been used by the Arbeitsgemeinschaft für Osteosynthesefragen (AO) foundation for over 50 years[56]. Specific to this thesis, models that have been used for arthroscopy are reviewed in the simulator section.

A study from the United States of America (USA) used an electronic survey to canvass the frequency and perceived effectiveness of 10 types of adjunctive arthroscopic skills training tools[55]. The responses from orthopaedic residents, residency program directors and orthopaedic sports medicine attending physicians showed 9.8% of programs had access to virtual reality training for arthroscopic skills development. Cadaveric simulation was viewed as the most effective and preferred method of training.

It should be re-iterated that a surgeon's training does have a significant component that involves procedural training, but this is alongside other non-procedural aspects training [20,37]. This thesis deals only with the procedural aspects related to shoulder arthroscopy.

Current methods of arthroscopic skills assessment

Ultimately, the purpose of surgical training is to produce a surgeon who is able to perform operations. This introduces the concept of competence. Historically, competence has been bestowed to trainees by senior surgeons, who themselves have gained competence through experience and peer-review[57–59]. This definition of competence is highly subjective. The inability to define competency and quantifying arthroscopic proficiency has been recognised[35]. Training programmes are adopting more competency-based models, in which objective skills assessment are required for trainee progression[15,36].

In the UK, the Joint Committee of Surgical Training (JCST) mandates a trainee to have performed a minimum of 40 arthroscopic procedures spread across all joints (knee, shoulder, hip and ankle) under supervision over the course of a training programme (6 years) [44] to be eligible for the Certificate of Completion of Training (CCT).

The competence level now relies more heavily on defining performance. Performance needs to be measurable in order to show progress along a learning curve and plateauing at the same level as an expert. This requires a form of assessment, which broadly can be subjective or objective. Assessment methods on performance have been criticised and continue to evolve.

For the method of assessment to be deemed applicable, it must show feasibility, reliability, and validity[60]. Validity is described in more detail in a later section.

Subjective assessment

Subjective assessment of a trainee is the simplest and earliest form of assessment. It follows similar principles to an apprenticeship, where a trainer will give their trainee or apprentice a global assessment[35]. It has been shown this form of assessment does not reflect the actual level of skill the trainee may possess[11,15]. The actual global assessment of a trainee's situational performance is also a reflection of the assessor's/trainer's own experience of that particular scenario[61]. For a surgical trainer, that could be the experience of managing patients with a specific type of pathology and the level of complexity[35].

To improve the assessment of a trainee's skill, more objectively-based assessment tools have been developed [35,55,58,62–65], whilst remaining feasible and practical[37,66]. These are discussed below.

Competence by numbers

A learning curve is established and maintained at a plateau if a skill is continuously practiced[43,45]. This does not define competence, but it does make the assumption that the majority of novices should achieve the same skills performance plateau of experienced surgeons with continued practice[43,45]. Little evidence exists on how skills acquired in one joint environment actually transfer to another joint. This raises questions surrounding the suitability of modern training programmes at delivering sufficient arthroscopic competencies across the various different anatomical sites encountered in treating patients[44].

Similarly, the Arthroscopy Association of North America (AANA) does not quantify competence, but requires that 50 arthroscopic cases be performed annually to maintain active membership[67]. The American Board of Orthopedic Surgery (ABOS) requires a one-year accredited ACGME sports medicine fellowship and at least 75 arthroscopy cases to be eligible for subspecialty certification in sports medicine[68].

The assumption that every novice will progress along a learning curve and performance will plateau at the same level as an expert has been challenged in both arthroscopy[46,47]and laparoscopy[48]. Hence, it is not appropriate to rely solely on competence by numbers[57,59].

Objective assessment

To address the limitations of the above methods of assessment for arthroscopy, more objective methods of assessment has been developed. This allows objective feedback thus allowing for the transition from an apprenticeship-based method of training to a more competency-based training[58,62].

Objective assessment tools described can be broadly defined into:

1. Quantifiable outcome measurement: such as mean time to perform the task, force measurements and motion analysis.

2. Procedural checklists/Global ratings scores (GRS): categorical subjective assessment of defined intra-procedural steps.

A recent systematic review in 2016 highlighted 13 studies that evaluated measurement outcomes for knee arthroscopy training[69]. The outcome measures used:

- Mean time to perform the task in all 13 studies.
- Navigation and triangulation based tasks in 10 studies.
- Cartilage collision and surgical force in 6 studies.
- Hand movement/motion analysis in 3 studies.

In shoulder arthroscopy, outcome measures that were able to discriminate skill level on shoulder simulators[7,10,70,71] include:

- Time to completion of tasks.
- Distance and path travelled by probe.
- Number of probe collisions.

Force measurement evidence

Iatrogenic damage during arthroscopy can occur when there is inadvertent collision with intra-articular structures or during portal placement[10,11,15]. The surgeon will get tactile feedback when the inadvertent collision is made. Therefore measurements of force when a collision is made and the number of collisions provides an objective method of evaluating tactile surgical performance[35]. This method of objective assessment has been shown to correlate with level of knee arthroscopic experience, with fewer collisions and lower collision forces noted in experts compared with novices[72,73].

Motion analysis evidence

Motion analysis assesses hand or instrument movement with the assumption that a surgeon with a higher skill level will minimise unnecessary movements and proceed with a higher probe velocity[7,37,73–75]. The novice will still exhibit excess and often unnecessary hand or instrument movements[74,75]. Validation studies have shown motion analysis is a valid assessment tool in determining skill level[37,73,76–78].

It could be used as an adjunct to more traditional methods of assessment[35,37,52,74,75,79–81]. It helped identify that a subset of medical students failed to achieve competence despite sustained practice[46,47], supporting the notion that competency by numbers may not be achieved by all those who practice. There are however associated equipment costs and limitations in that validation has only been shown performing basic arthroscopic tasks[35,37].

Global Rating Scales (GRS)/ Task or Procedure-specific checklist evidence

These systems all rely on the principle of scoring against preset criteria by trained assessors. The checklist contains essential elements of a procedure, whilst the GRS focuses on specific surgical behaviours[53]. These have been shown to superior to direct observation by experts alone[82,83].

Global rating scales assess performance across several domains to generate an overall performance rating in simulated and clinical settings[62,84–87]. They are attractive as they are generic, easy to use in terms of lack of additional equipment, applicability to multiple tasks and usability in the operating room[62]. They have been used across different surgical specialties[82,84,88,89].

In orthopaedics, GRS has shown to have the ability to assess skills levels and learning curves [35,58,63]. There are different GRS including the Arthroscopic Skills Assessment Form and OAAS[35] and Arthroscopic Surgery Skill Evaluation Tool (ASSET) [55]. The different GRS have similarities in the assessment and domain and anchors. This has unsurprisingly resulted in similar scores and thereby similar differences between skill levels[62].

The performance of global rating scales assessment have correlated with motion[76–78].

Similarly, procedure-specific checklists have been well described in other specialties[90–92]. The gold standard for objective skills assessment in the Structure Assessment of Technical Skills (OSATs)[64]. A modified version to assess knee arthroscopy demonstrated transfer validity to the operating room[65]. Checklists include the Orthopaedic Competence Assessment Project (OCAP)/ISCP Procedure Based Assessment[34]. Procedure based checklists have been reported to have an inferior construct validity and weaker interrater reliability compared to GRS[93]. Task specific checklists are the least powerful of the tools, in that they are applicable to a single task and have demonstrated early ceiling effects[58,94].

The Basic Arthroscopic Knee Scoring System which is a 2-part assessment with a task-specific checklist and a GRS component[58]. This has the ability to differentiate between levels of arthroscopic experience[58].

Drivers for new training methods

Training methods will continue to evolve as evidence accumulates around new methods of learning and with the advancement of technology and innovation. There are also drivers for change, such as

1. Minimising patient harm and associated litigation.
2. Consensus for the need to be able to objectively define surgical performance
3. Standardising training and identifying training requirements.
4. Improving hospital efficiencies.
5. Responding to enforced working time directives.

Minimising patient harm and associated litigation

UK national initiatives such as the National Joint Registry (NJR) and the National Hip Fracture Database (NHFD) now collect data that can identify and report back at hospital level regarding performance[95,96]. The NJR also releases data to the public on individual surgeon's performances. Although arthroscopic procedures are not compulsorily recorded, the National Ligament Registry (NLR) voluntarily collects information about some knee ligament reconstructive arthroscopic operations and also the clinical outcome[97]. Surgeons are under increasing pressure to demonstrate competence in an objective manner to both peers and to the public[8,98].

Litigation arising from accidental injury from orthopaedic surgery causes substantial costs to the NHS[3]. As identified earlier, it has been shown that surgeons in the early phase of their arthroscopic skills learning curve have an increased risk of iatrogenic injury[6,10,49].

Consensus to objective define surgical performance

The difficulty to define a competency level has been discussed earlier. It is accepted that in order to be able to set up a competency level, an objective measure of surgical performance needs to be achieved[12–15]. Although several methods of objective measurements have been reviewed, no ideal parameter has been identified in isolation. It is likely that a combination of techniques will be required.

There is also recognition that such techniques may be used not only for assessment during training, but also for accreditation[9,35].

Standardising training and identifying training requirements

There are limitations of a traditional apprenticeship model, notably it lacks the objective assessment and also the process can be inefficient particular in terms of time and cost[4–7,10,11,15,18]. This challenge is compounded by the implementation of work-hour restrictions (discussed below), to the stage that the adequacy of traditional arthroscopic training during residency has become an increasing concern [21,22,62,99].

If there is national variation in training methods, this also makes it difficult for the JCST to provide a benchmark for trainees to compare their own training progress against their peers (Personal communication with the British Orthopaedic Association (BOA) Simulation Working Group).

Objective assessment may help plot a trainee's learning curve and help determine whether their performance has plateaued. This performance plateau can then be compared with an expert to see if similar competence (as measured by that specific performance parameter) has been achieved. This helps identify those individuals whose performance parameter do not plateau at the level of an expert[48]. This can allow appropriate feedback to the trainee and the implementation of supportive measures, either through extended training time and additional training methods. The current evidence does not support the use of such assessments to be used as a screening tool in identifying individuals who may not possess the technical skills necessary for a career in orthopaedic surgery[46]. Other parameters can be important in identifying surgical performance, including the performance of the entire surgical team, age, and personality traits[100–102].

Improving hospital efficiencies

Hospital managers often are in charge of improving theatre utilisation. The effect of training a junior surgeon often results in a longer operative time, which can translate into a longer theatre session. In other words, for the same amount of theatre time, less surgical procedures can be done. This has an effect on patients, surgeons, trainees, surgical and managerial staff.

By allowing trainees to train outside the theatre, trainees will require less operative time to gain the same level of operative skills[20]. The more efficiently a trainee can perform simulated surgery outside of the theatre setting, the closer the operating theatre time will be to expert-level efficiency. This minimises the effect on patients, staff and also the finances within the health services[3].

Responding to enforced working time directives

Enforced limits on working hours has been introduced internationally[25,103] aiming to improve patient safety and reduce tiredness amongst doctors and healthcare staff[23–26]. Although the working time has reduced, this also has had a negative effect on training time[62,99]. To maintain existing services with a workforce that has hours that are capped means that staff numbers need to increase, and this again has a negative impact on opportunities to develop procedural and technical skills as more trainees are competing for the same procedural training[20].

It is believed that for surgical training, the decreased training time in the operating theatres has limited opportunities by two-thirds[104,105].

An overview of simulation

The definition of simulation is constantly evolving[20,32,33,106] and there is no clear definition of orthopaedic simulation. Within the medical field, simulation has been broadly defined as "any technology or process that recreates a contextual background in a way that allows a learner to experience mistakes and receive feedback in a safe environment"[107].

Benefits

The benefits of simulation are well recognised in many specialties including general surgery[52], emergency medicine[108] and anaesthetics[109]. Trainees can concentrate in a controlled environment on skills acquisition[15,52]. Work is already underway for the 2018 UK orthopaedic specialist curriculum where simulation is likely to feature heavily (Personal communication with the BOA Simulation Working Group).

Limitations

There still remains limited evidence regarding transfer validity of simulation methods into theatre[20]. It is also accepted that even the most complete and validated training simulators cannot recreate and develop all the different components a surgeon will encounter[20]. It is critical that trainees and trainers remember that technical ability forms only one component of the skill set required to be an accomplished surgeon[20,37]. Whilst simulation may facilitate in the challenge of gaining sufficient technical aptitude, it fails to address other essential components: clinical experience, decision making and attitude'[20,37].

Types of Simulators

Broadly, simulation can be divided into: [110]

1. cognitive simulation
2. skills simulation
    a. technical skills, such as operative techniques.
        i. High-fidelity simulation: defined as the ability of the simulation to represent highly realistic performance features, environments and circumstances.

ii. Low-fidelity simulation: defined as simulation that exemplifies simpler constructs or components of the skill needed to be learned.

b. non-technical skills, such as communication and leadership skills, not discussed in this thesis.

Cognitive simulation has been used in other scenarios such as elite sport[111]. This type of simulation is one of the newest examples of innovation within surgical training with limited evidence of transference to surgical ability[20,112]. Cognitive simulation does not focus on the development of physical skills, but focusses on trainees to rehearse stages of the operation without physical movement[20]. This could be in the individual's mind, or openly discussed with the trainer, or using props or technological aids with the aim to ultimately increases the awareness of potential complications[20].

There is evidence that neural pathways that are stimulated from imagined muscle movements can be as effective as physical practice[113]. The Association of Surgeons in Training (ASiT) in the United Kingdom has recognised the potential and cognitive simulation courses have been delivered with positive feedback[114]. If proven to be effective, cognitive simulation could provide a low-cost, easily accessible tool that can be applied to multiple different procedures without the need for specialist equipment[20]. Rehearsal of procedures is now possible using mobile simulation software applications[54,115].

For technical skills simulation, an example of high fidelity simulation would be cadaveric surgery[11]. A human cadaver would have unparalleled accuracy in anatomy and tactile tissue feedback[35]. Synthetic models may fall in between high and low fidelity simulation as models can allow increasing detailed anatomical accuracy without the maintenance or ethical issues, but have been criticised for a lack of face validity[116]. Low fidelity simulation include the basic fracture management courses run using synthetic bones, such as the Arbeitsgemeinschaft für Osteosynthesefragen (AO)[56].

There is no evidence one is more superior than another in terms of improvement in task performance[69,117] and it is likely that the type of simulation chosen will be based on cost, support, supervision and access.

A review of the literature has identified different types of technical skills simulation in arthroscopy. These can be summarised as:

1. Synthetic
2. Computer
3. Virtual Reality
4. Cadaveric

Synthetic

Artificial models can be split into non-anatomical and anatomical simulation. Non-anatomical models tend to concentrate on task-based training, so that the core principals, such as visualisation, triangulation and tactile feedback can be learned[37]. They are less suitable for other parts of arthroscopy, such as positioning and also requires supervision and guidance by a senior surgeon[37]. In arthroscopy, most synthetic models come as a box-trainer which provides a simple, cost-effective and accessible form of training[37]. Box trainers contain the same core features:

1. Outer shell with holes providing access to the inner working area and act as the fulcrum for the camera and intruments/tools.
2. Inner working area (varying complexity).
3. Equipment: always camera in one hand +/- instrument/tool in the other hand

The inner working area consists of tasks of varying skill levels. An example of a commercially available box trainer is shown in Figure 10.

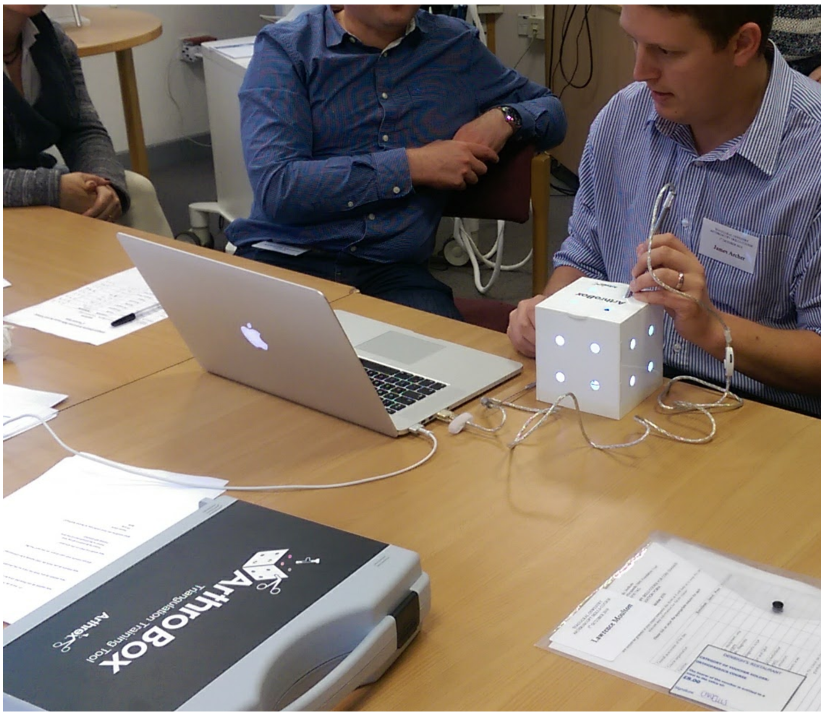

Figure 10: Commercial box trainer (Arthrobox® by Arthrex, Naples, FL, USA).

The instruments used can be real instruments used within surgery[20] or can be alternatives. It is likely that real instruments will have a knock-on effect and increase the overall cost of the simulation, but allow the trainee to develop familiarity with the equipment[118]. This experience has shown to transfer well into the operating room[20]. Typically, such box trainers would be dry, however models which simulate water flow in arthroscopy have been tested (wet box simulators) [61,119–122].

The introduction of synthetic and plastic bone models have the advantage of anatomical reproducibility without maintenance or ethical issues[116]. The anatomical models allow the trainee to experience the working area in relation to surrounding structures. The structures may limit the task or be of significant importance where damage could significantly compromise surgical outcome. One such mode is the Alex Shoulder model which has been superseded by the Alex Shoulder Professor III Model[123]. The models have a natural wear rate, so the more simulated tasks are performed, the increased wear of the anatomical components. These components are often manufacturer-specific and require custom order at increased cost. Similar to the box trainers, there often is no inbuilt mechanism of assessment and so feedback requires supervision[124].

Computer (motion analysis/haptic feedback) and VR

Computer-based simulators are evolving from the experimental stages with established construct validity in knee and shoulder arthroscopy[65,73,125–127] The development of less expensive high performance computers combined with advances in graphical and force-feedback technology (haptics) has accelerated this movement [35]. Motion analysis, force collision and accurate timing of task performance allows for objective data to be collected and feedback provided[7,10,11,15,70–73].

Improved face-validity in simulators both in terms of graphics and equipment has resulted in the high-fidelity computer models being termed virtual reality (VR), although the distinction between the two is not clear. Software required to run VR simulators can be installed on most modern computers, but the input devices are usually very specialised.[128]

Virtual reality simulators have a built-in means of objective assessment, such as task completion times, instrument handling efficiency and motion path analysis[37,124]. Surgical VR simulation has emerged at the forefront of technologies and processes in the education and training of surgical residents, with high expectations. [3]

Examples of VR arthroscopy simulators include the Insight Arthro VR (GMV, Madrid, Spain), now known as Simbionix Arthro Mentor (Simbionix Ltd., Aiport City, Israel), Procedicus arthroscopy simulator (Mentice, Göteborg, Sweden), Sheffield Knee Arthroscopy Training System (SKATS; University of Sheffield, Sheffield, England) and Virtual Environment Knee Arthroscopy training system (VE-KATS; Castle Hill Hospital, Hull, UK).

Cadaveric

Human cadavers remain the highest fidelity simulator model[11]. In addition to superior anatomical and tissue characteristics, fresh frozen cadavers can reproduce conditions during an arthroscopy, such as fluid management, and equipment use[58]. It remains the gold standard teaching platform in instructional courses[35].

The limitations of cadaveric use include the risk of disease transmission, high cost, prolonged preparation time and storage leading to inefficiency, variability in anatomy and pathology between cadaveric specimens all of which affect its availability in education centres[6,10,129,130].

Perhaps of greatest significance is the discrepancy of evidence relating simulated cadaveric techniques with operating performance in theatre[20].

Validation studies into arthroscopic simulation

Validity has been described[60] as

> *"the extent to which the assessment tool can accurately measure what it is designed to measure and consists of 5 dimensions:*
>
> 1. *construct,*
> 2. *content,*
> 3. *predictive/transfer,*
> 4. *face,*
> 5. *concurrent."*

The definitions of these types of validation has been provided below[33,60]:

Construct validity: the extent to which a test measures what it sets out to measure. A specific inference of construct validity is the ability to differentiate between subjects of varying levels of experience

Content validity: ensure that the important domains of simulation are covered and the content criteria have the appropriate relevance (eg appropriate surgical skills)

Predictive/Transfer validity: extent of the simulator to enhance trainee's performance with continued use.

Face validity: describes the degree to which the simulator looks like the clinical setting

Concurrent validity: correlation between the results of the simulator and another system or assessment tool on a certain domain

Construct validity studies

The simplest method to perform a construct validity study is to compare a minimum of 2 groups of known skill levels based of real-life arthroscopic experience, such as experts and novices[19,32,45,131,132]. The performance at arthroscopy is accepted to be different (and not tested) and the study's objective assessment method is assumed to be valid if it reliably identifies individuals belonging to the correct group, i.e. novices perform at novice level, and experts perform at expert level[19]. Construct validation is by far the most common method of validation in arthroscopic simulation literature at present.

The majority of the studies show that the simulator tested does show construct validity between novices and experts, but there are some studies which highlight the difficulty in differentiating between the intermediate levels[7,38,127]. Discrimination between novice and intermediate trainees in surgical education should be paramount[19,35]

Experienced surgeons have achieved better results in performing VR-simulated arthroscopic tasks compared to novices as measured by one or a combination of time to complete a procedure, computer-assessed motion analysis compared with a predetermined optimum and number of probe collisions [7,10,37,38,73,118,133].

Table 1 summarises the evidence by simulator category type (synthetic, computer, VR, cadaveric).

	Construct validity shown?	
	YES	NO
Synthetic	[63,73,118,134,135]	
Motion/haptic	[7,10,37,45,65,73,126,127]	
VR	[7,10,19,32,37,38,45,65,73,118,121,126,127,131–133,135–139]	
Cadaveric		

Table 1: Summary of construct validity evidence by simulator category.

Content validity studies

The aim of content validity is to ensure the important domains have appropriate relevance, and for arthroscopy this is appropriate surgical skills. It is not surprising that most studies looking at content validity have involved the high fidelity simulators which are more life-like and have shown appropriate relevance.

Table 2 summarises the evidence by simulator category type (synthetic, computer, VR, cadaveric).

	Content validity shown?	
	YES	**NO**
Synthetic		
Motion/haptic	[121]	
VR	[38,71,140]	[110]
Cadaveric	[137,139]	

Table 2: Summary of content validity evidence by simulator category.

Predictive/transfer validity studies

Predictive or transfer validity aims to investigate how a trainee's performance changes with continued use. This can be measured in 2 ways:

1. effect on performance on the simulator,
2. skills transfer into theatre

The difficulties to measure performance have already been discussed, and so objective measures form the basis of this type of study. The majority use objective measures such as motion tracking, collision force and time taken to complete performance. Motion tracking can be used within a virtual environment (VR simulators) or during the use of synthetic simulation. VR simulators can measure collision data such as force and depth of collision alongside parameters of basic arthroscopic skills, such as navigation and triangulation (camera and instrument motion paths).

The majority of studies show that with repeated practice, individuals perform better on the performance task being assessed. However, some studies have shown that performance did not improve with repeated practice[32,41,44,133,136,140]. A possible explanation for the findings is that the individual may not have the aptitude to develop these skills. Another interesting point raised in one study showed that although developing skills in one particular anatomical environment, this may not translate into another simulated environment, for example training on a shoulder arthroscopic simulator may not increase performance on a knee arthroscopic simulator[44].

There is quite a heterogeneity of results when it comes to results of studies looking at transfer of skills into theatre. Primarily the problem lies in measuring intra-operative surgical performance. A possible explanation for the disparity in results from the different studies may be that the skills taught by a simulator may be too specific for the procedure itself[41]. The difficulties of measuring intra-operative performance have been discussed before, and as a result the majority of studies use a form of global rating scales to help objectify surgical performance.

Table 3 summarises the evidence of effect on performance by simulator category type (synthetic, computer, VR, cadaveric).

Table 4 summarises the evidence of skills transfer into theatre by simulator category type (synthetic, computer, VR, cadaveric).

	Predictive/transfer validity for skills on simulator?	
	YES	**NO**
Synthetic	20,37,43,45,134	44
Motion/haptic	37,45,73,121,136	
VR	3,10,32,38,43,63,70,133,136,140,141	41,44,71,135
Cadaveric		

Table 3: Summary of predictive/transfer validity evidence by simulator category for skills learned on the simulator.

	Predictive/transfer validity for skills in operating room?	
	YES	**NO**
Synthetic	20	
Motion/haptic	37,65,73	
VR	7,37,38,46,65,135,137,142	19,32,41,136,143
Cadaveric		20

Table 4: Summary of predictive/transfer validity evidence by simulator category for skills learned on the simulator.

Face validity studies

Face validity refers to ability of the simulator to look like the clinical setting. There are 2 key components for arthroscopic simulation – external face validity and internal face validity. External face validity refers to how the simulator looks on the outside and how it represents the external anatomy of the joint. The internal face validity refers to the visual information displayed on the screen during arthroscopy. This maybe a tangible visualisation, such as in synthetic models or maybe a virtual representation like in VR simulators.

There is no objective method of measuring face validity, but the most common method is along the principle of the Likert scale[144]. This is a scale between 1 and 5 (or 10) and the user rates the face validity of the simulator. It attempts to objectify the assessment but has little in the way of an objective criteria defining the anchor points within the scale. There is no consensus of when a simulator achieves face validity and it is difficult to compare studies.

In general, most simulators had some external face validity, however the internal face validity was highest in the VR and cadaveric simulators. It is also worth noting that cadaveric simulation in particular can also allow simulation of fluid management, the light source, and shavers, the usefulness of which should not be underestimated[58].

Table 5 summarises the evidence by simulator category type (synthetic, computer, VR, cadaveric).

	Face validity shown?	
	YES	**NO**
Synthetic	[118]	[145]
Motion/haptic	[122]	
VR	[38,121,122,133,146]	[132]
Cadaveric	[58,145]	

Table 5: Summary of face validity evidence by simulator category.

Concurrent validity studies

Concurrent validity investigates the use of a new simulator against an established validated simulator. The most common method is to use a simulator that has achieved construct validity and then test for concurrent validity.

Positive correlations have been found between:

1. VR and cadaveric simulation[70,147].
2. Motion tracking (computer) and synthetic model simulation[37].

Interestingly when comparing haptic and non-haptic features on a VR simulator, no difference in performance was noted suggesting that the haptic feature did not add as much effect on performance as previously envisaged[53].

Practical pressures limiting uptake of simulation

The advantages of simulation in acquiring arthroscopic skills have been discussed, however the practical application of these training techniques have limited its widespread use.

Synthetic models lack the objective parameters of performance and hence rely on supervision from senior surgeons for feedback. This could be in real time or recorded and played back at a later time. Performance can then be assessed using tools described earlier. The costs associated with this include purchasing/leasing costs and replacement of parts. Time for senior surgeon's time to assess and deliver feedback also needs to be factored in.

Building on this, technology such as motion analysis and collision forces allows more objective feedback. Computer models are highly objective since they use internal metric calculations and are assessor independent. They have few ethical considerations but have generally been costly, require fixed training facilities, and need specialised technical support[105]. The objective measures recorded have been validated for basic arthroscopic tasks only, which may limit its ultimate use[35,37].

VR simulation has now adopted much of the technology from computer models and with more realistic input devices and visual graphics, represents the highest fidelity non-cadaveric simulator. It does come at a very high price (approximately US $100,000 from personal communication), often making it cost-prohibitive for most institutions. Such high cost investments are subsequently protected from out of hours' open access training, principally out of fear of inadvertent damage. This limits wide-spread access to trainees.

Cadaveric simulation represents the gold standard in arthroscopic simulation. However, the limitations include risk of disease transmission, cost, preparation time, storage and variability anatomy and pathology. This means that this is cost prohibitive and makes it difficult to standardise training. Assessment relies again on non-objective parameters such as GRS or checklists and subsequent feedback will require time from senior surgeons.

Need for ASATs (Identification of Necessity for this study)

It is clear from the literature review that a measure of objective performance is required to form the basis of performance. All the simulators reviewed that truly measure objective parameters (such as motion analysis and force measurement) have high costs and restrictive access. As has been seen, GRS or checklists have attempted to objectify performance but are not truly measuring objective parameters.

To address these limitations, MJG developed and funded the Arthroscopic Skills Acquisition Tools (ASATs) prototype. This serves to provide objective parameters to measure performance, and be widely accessible at low cost to the end-user.

Introduction to the ASATS

The ASATs has been designed as a low cost and easily accessible training and assessment tool for arthroscopy surgical trainees. To minimise cost and maximise access, a decision was taken to limit the user interface to those available via a standard PC (keyboard and/or mouse). The decision to limit the user interface hardware in this way meant that face validity was likely to be low.

Objective feedback identified from the literature can be based on motion tracking, haptic/force measures, or surrogate markers of visualisation and triangulation (such as time and look downs).

The ASATs had to be designed using software that was widely accessible and free. Adobe Actionscript Technology (http://www.adobe.com) was chosen, as at the time it was widely accessible, free and available on internet-enabled computers and can be embedded into websites. For motion tracking, it was decided to use 2-dimensional mouse movement.

Haptic/force measurements could not be mimicked using simple hardware. Instead the concept of error-based measurements was conceived. In arthroscopy, a large force through an area that is pressure-sensitive (e.g. cartilage) would result in damage. This would be an error. Simply put, the user would have ignored the haptic feedback and pursued through this feedback into an area which they should not have been. The decision was made that as the haptic feedback could not be reproduced, the same concept in visual format would be made. This meant that there was an area of the screen which represented the working area. By ignoring the working area and going into the "out of working area" you are ignoring the visual feedback and causing damage. Although not exactly the same, it created an "error-based" measurement which could be measured on the ASATs.

Surrogate markers of visualisation and triangulation included time to complete the task. This could be easily incorporated into the ASATs. However, the dangers of using this measure alone are evident, the fastest surgeon does not necessarily mean they are the best or most careful!

In summary, the ASATs priority objective measures were time-based, motion-based and error-based. Motion-based was represented by the distance moved by the mouse pointer, rather than hand motion.

With these objectives clearly stated, 3 ASATs were designed. A mouse pointer is displayed in all the ASATs, and this resembles the centre of the arthroscopic camera view. The layouts of the tools are designed to be consistent (Figure 11): a white working area represents the joint space and the surrounding blue area represents the area outside the joint. Crossing the mouse pointer from the white area into the blue area is designed to serve as visual feedback that the camera is causing damage in the absence of haptic feedback.

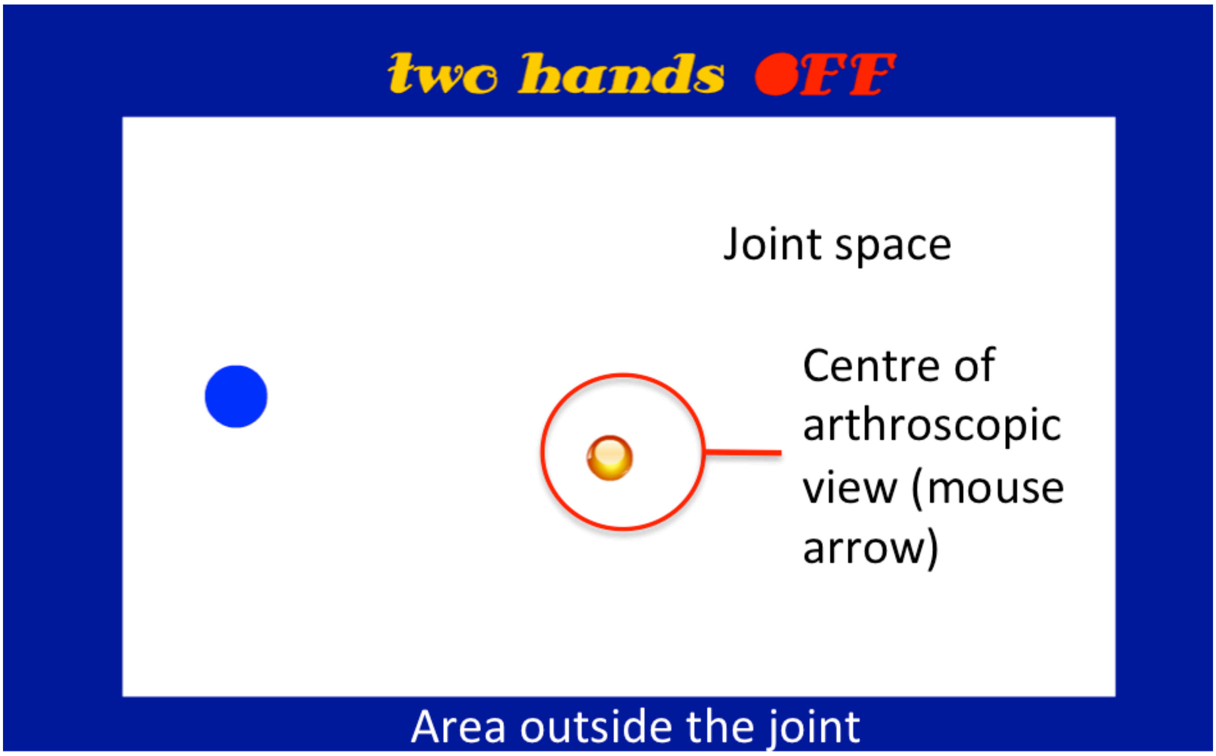

Figure 11: Layout of the ASATs.

The "track box" ASAT was designed to test steady, accurate tracking movements within a fixed time. The "click points" ASAT was designed to test small but fast and accurate movements between multiple fixed points.

A third ASAT ("shape match") builds on the "click points" ASAT and requires lifting and releasing shapes within the working area. This requires users to move shapes from one part of the "joint" to another marked area of the "joint" by holding the shape with the left mouse button and dropping the shape by releasing the button. The task is complete once all the shapes have been moved into their corresponding silhouettes.

A further three ASATs were then designed with the input controls inverted ("track box", "click points", and "shape match", all with inverted controls). This mimics the inverted hand-eye controls experienced with arthroscopy. These tools formed the final six ASATs (Table 6).

<table>
<tr><th>ASAT</th><th>Objectives</th><th>Skills required to complete task well</th></tr>
<tr><td>Track Box</td><td rowspan="2">Keep the mouse pointer over the moving box</td><td>Hand-eye coordination
Steady, accurate movements</td></tr>
<tr><td>Track Box with Inverted Controls</td><td>As above and
Ability to invert coordination skills</td></tr>
<tr><td>Click Points</td><td rowspan="2">Move the mouse pointer over the static point, and left click. The point will disappear and reappear somewhere else. Repeat until all points have been clicked.</td><td>Hand-eye coordination
Reaction speed
Small, fast, accurate movements</td></tr>
<tr><td>Click Points with Inverted Controls</td><td>As above and
Ability to invert coordination skills</td></tr>
<tr><td>Shape Match</td><td rowspan="2">Move the mouse pointer over the static blue shape, and hold down left click button to pick up the shape. Move the pointer and shape into the matching grey shape and then release left click button.</td><td>Hand-eye coordination
Steady, accurate movements
Reaction speed
Small, fast, accurate movements</td></tr>
<tr><td>Shape Match with Inverted Controls</td><td>As above and
Ability to invert coordination skills</td></tr>
</table>

Table 6. Summary of the prototype Arthroscopic Skills Acquisition Tools (ASATs). "Shape match with Inverted Controls" was used as the assessment ASAT in this correlation study.

Users can perform each ASAT with the scope view, two-handed input, or obstructions options either on or off resulting in 30 variations of the tools. For the purposes of this study, the advanced options were standardised (open view = scope view off, single hand input and obstructions off) and so the advanced functionality are not discussed further. The input devices for the ASATs are the mouse (single hand).

Each time any of the ASATs are accessed, the motion path of the box or the positions of the circles and shapes are random, which ensures that users develop skills rather than simply memorise the paths and positions of the box and points.

The objective data measured by the ASATs is saved to an online database to allow subsequent use on a different computer. The ASATs are currently embedded in a database-driven website, and the online ASATs homepage requires users to register for a username by completing a demographic questionnaire. All interactions with the ASATs occur in real-time. All performances and attempts on each tool are saved according to the username.

Using the Adobe Actionscript software, the following objective parameters could be measured.

	ASATs performance measures
Time-based	1. Time taken to complete the task A quicker time suggests the task was completed quicker.
Distance-based	2. Distance total – the distance the mouse moved in order to complete the whole task A larger distance total suggests the mouse moved more to complete the whole task.
	3. Minimum distance* - the minimum theoretical distance the mouse could be moved to complete the whole task (computer calculated) A larger minimum distance suggests the shapes were further apart at the start of the task.
	4. Delta distance** - calculated value by subtracting the "minimum distance" from the "distance total". This gives the excess movement the user required to complete the task. A higher delta distance suggests the user had excessive movement to complete the task.
Error-based	5. Out-time – percentage of task time the mouse pointer not in the working area A high out-time suggests the user spent more time ignoring visual clues and was in the non-working area of the task.
	6. Out-number – number of times the mouse pointer crossed into the non-working area (ignoring the visual feedback).

	A high out-number suggests the user ignoring visual clues and was crossing into the non-working area of the task. Combined with out-time, a high out-time and out-number would suggest someone who regularly making errors and not quickly correcting.
	7. On-box – percentage of task time the mouse pointer stayed over the shapes of interest. A high on-box percentage suggests the user was accurate in their mouse movements.
	8. On-work – percentage of task time the mouse pointer stayed in the working area. A high on-work percentage suggests that the user was not as accurate as a high on-box percentage, but was not making the same level of mistakes as someone with a high out-time.
	9. Drop times – number of times the shape was dropped from the mouse pointer. A high drop time number means the user was unable to hold the shape and move, i.e. do 2 things at once.

Table 7: ASATs performance measures. * = not related to user performance and so was not used for statistical analysis. ** = not objectively measured but calculated from 2 measures that were objectively measured, this parameter was used for statistical analysis.

This thesis aims to demonstrate the value of the ASATs by investigating the concurrent validity with a simulator which has been validated to shoulder arthroscopy. The simulator chosen to validate against was the Insight Artho VR system (GMV, Madrid, Spain). This VR simulator has been shown to have construct, content, face, transfer validity, as well as concurrent validity to arthroscopic performance in cadavers[70,135,148]. An introduction to this VR simulator is made below.

Introduction to the Insight Arthro VR Simulator

The Insight Arthro VR uses a life-size plastic shoulder with pre-defined portals. The VR simulator can allow the user to perform multiple tasks. Some tasks can be performed with the camera only and others with both a camera and an instrument. Simulations can be performed in either "beach chair" or "lateral decubitus" positions. This gives the simulator excellent external face validity. Each task had an "low", "intermediate" and "high" difficulty setting.

The tasks available on the simulator can be broadly divided into tasks within a non-anatomical environment or an anatomical environment. Non anatomical environment tasks are designed to develop basic hand-eye coordination skills. The anatomical environment has VR graphics which represents a joint (either shoulder or knee), thereby giving the VR simulator internal face validity. The tasks in the anatomical environment are designed to improve procedural skills (transfer validity).

The input devices consist of two robotic arms that provide haptic feedback to the user. Four tasks where chosen (1 non anatomical and 3 anatomical), and this is discussed in more detailed later.
Figure 12 shows a photo of the Insight Arthro VR (now known as Simbionix Arthro Mentor).

Figure 12: Insight Arthro VR (GMV, Madrid, Spain), now known as Simbionix Arthro Mentor (Simbionix Ltd., Aiport City, Israel).

The VR can record the following objective performance measures:

	VR performance measures
Time-based	1. Time taken to complete the task A quicker time suggests the task was completed quicker.
Distance-based	2. Camera Covered distance – motion analysis recorded by the robotic input arms. A large camera covered distance suggests the user moved the robotic arm representing the camera through a larger distance to complete the task.
	3. Probe covered distance – motion analysis recorded by the robotic input arms. A large probe covered distance suggests the user moved the robotic arm representing the probe/instrument through a larger distance to complete the task.
Error-based	4. Camera roughness – motion analysis recorded by the robotic input arm when the user is given increased haptic feedback. A large camera roughness suggests the user moved the robotic arm representing the camera in the direction of increased haptic feedback, and did not correct and the increased haptic feedback persisted. This represents a collision and/or damage of structures.
	5. Probe roughness – motion analysis recorded by the robotic input arm when the user is given increased haptic feedback. A large probe roughness suggests the user moved the robotic arm representing the probe/instrument in the direction of increased haptic feedback, and did not correct and the increased haptic feedback persisted. This represents a collision and/or damage of structures.

Table 8: VR performance measures.

Thesis aims

The aim of this thesis is to provide the initial validation of the Arthroscopic Skills Acquisition Tools through a concurrent validation study with the Insight Arthro VR simulator.

If concurrent validation were to be achieved, the expected correlations are as follows:

	Performance measures on		Correlation
	ASATs	**VR**	
Time-based	Time taken	Time taken	Positive
Distance-based	Distance total	Camera Covered distance	Positive
	Distance total	Probe covered distance	Positive
	Delta distance	Camera Covered distance	Positive
	Delta distance	Probe covered distance	Positive
Error-based	Out-time	Camera roughness	Positive
	Out-time	Probe roughness	Positive
	Out-number	Camera roughness	Positive
	Out-number	Probe roughness	Positive
	On-box	Camera roughness	Negative
	On-box	Probe roughness	Negative
	On-work	Camera roughness	Negative
	On-work	Probe roughness	Negative
	Drop times	Camera roughness	Positive
	Drop times	Probe roughness	Positive

Table 9: Expected correlations between the "shape match with inverted controls" ASAT and VR tasks.

Chapter 3 – Methodology

Introduction

The study subjects were novices in the technical skills of minimal invasive surgery, such as laparoscopy or arthroscopy. Inclusion and exclusion criteria, enrolment and participant information is given later on in this section. The participants were shown familiarisation videos of the ASATs and VR simulator. They were also given some time to familiarise on 5 ASATs before being tested on the 6th ASAT (shape match with inverted controls). Full details are in the procedure section.

A correlation analysis between objective parameters between the ASAT (shape match with inverted controls) and VR tasks were performed, and the results presented.

Research Design

This was an ethically approved, prospective study involving 49 medical student volunteers who met the inclusion criteria. A priori power analysis showed a total sample size of 33 subjects would be sufficiently powered to show a significant correlation. All participants underwent a standardised session. All data was collected in a single session at a single location. Correlation between the objective performance measures from the ASATs and the VR simulator were investigated using statistical software and the results presented in the next section.

Gaining Ethical Approval

National Health Service (NHS) North of England provided organisational approval and North Western Deanery provided Sponsor's approval on 17th September 2012.

This prospective study involved participants who were healthy volunteers. University of Salford approved an ethics application (HSCR12/67) on 19th November 2012. Wrightington, Wigan and Leigh NHS Trust's Research and Development Department provided email confirmation on 20th September 2011 that no NHS ethics application was required as no NHS patients were involved in this study.

Participants

Participants in the study were medical students for 3 specific reasons.

1. It would be expected that some knowledge of anatomy and indications for surgery would be realised by the participants.
2. Medical students were more likely to have been exposed to arthroscopic or minimally invasive surgery through videos or live operating theatre lists, but they were unlikely to have had any specific arthroscopic or minimally invasive surgery training.
3. At this stage of training, medical students were unlikely to have committed to a specialty, and so skills assessment could be made across differing specialty ambitions.

Inclusion Criteria

- 18 years or older.
- Able to provide consent to take part in the study.

Exclusion Criteria

- Any participant that previously received practical training or performed previous minimal invasive surgery, such as laparoscopy or arthroscopy.
- Were younger than 18 years old
- Unable to provide consent.

Recruitment

Study and participant information sheets (see appendix) were distributed through email distribution lists and society events held by the University of Manchester Medical School and Manchester's Scalpel Surgical Society. Information was also displayed on their relevant websites' noticeboards.

Participants were given the opportunity to discuss this study face-to-face, over the phone or via email.

Signing up to a study session

If students wished to take part, they were directed to a website to sign up for a 1-hour study session. The website contained information and a sign up form, powered by Google® and Appointy®. This displayed real-time session availability and allowed students to sign up for a session and receive confirmation immediately. It also sent out reminders prior to the session to improve session utilisation. All sessions were conducted at the Bridgewater Hospital, 120 Princess Road, Manchester, M15 5AT. All suggestions were run at no cost to the participant and no reimbursement for time or travel was offered.

Gaining consent

Each participant was given a participant information pack to review. This included an introduction to the study and written information and photographs of the ASATs and VR. Each ASAT and VR task objective was clearly explained. Once the material was reviewed, each participant was asked to confirm consent to participate in the study. Written consent was taken, and a participant unique identifier number (UIN) assigned.

Confidentiality

The UIN is used to identify individual's performance anonymously on both the VR simulator database and the ASATs database. To register for the ASATs, participants are required to fill an online registration form that includes a demographic questionnaire.

Procedure

Participant information sheets, descriptions and objectives of the VR simulator and the ASATs were printed and held in an A4 folder. Participants were allowed to review this as many times as they wished. The participants were then shown a video demonstration of the ASATs followed by a video demonstration of the VR system. There was an opportunity for participants to ask questions before performing the assessment tasks.

Assessments

Participants performed 5 ASATs tasks to familiarise themselves with the ASATs followed by a 6th final ASAT used for assessment. Following successful completion of the ASATs, participants progressed onto the VR simulator to perform 4 tasks.

ASATs tasks

The ASATs were performed on a 17” screen-size, internet-connected laptop computer using an external USB optical mouse with a standardised mouse mat available. The 4 ASATs tasks (and the options chosen) were performed in the following order:

1. “track box” with normal controls, “open view”, “single hand control”, “no obstructions”.
2. “track box” with inverted controls, “open view”, “single hand control”, “no obstructions”.
3. “click points” with normal controls, “open view”, “single hand control”, “no obstructions”.
4. “click points” with inverted controls, “open view”, “single hand control”, “no obstructions”.
5. “shape match” with normal controls, “open view”, “single hand control”, “no obstructions”.
6. “shape match” with inverted controls, “open view”, “single hand control”, “no obstructions”.

VR tasks

For this study, four tasks at “low difficulty level” were chosen and participants performed them in the following order:

1. “*operating room*” (non-anatomical), “camera use only”
2. “*locate and palpate*” (anatomical - shoulder), “camera and instrument use”.
3. “*visualise*” (anatomical - shoulder), “camera use only”.
4. “*pendulum*” (anatomical - shoulder), “camera and instrument use”.

Data Handling

Data Collection and Storage

Data was prospectively collected during a single session for each student. The data from the first attempt (baseline performance) on “shape match with inverted controls” ASAT was automatically saved to an online database (ASATs). The performance measures data on the four tasks performed on the VR was collected and automatically saved to a local database based on the simulator computer (VR).

Data Retrieval

The ASATs has a download function, and the data collected is downloaded in a spreadsheet. The VR simulator has an export function and the data collected is presented in a spreadsheet. This is saved onto a USB hard drive and then transferred to a computer for statistical analysis.

Once data from both simulators are available, they are amalgamated into a single database, using the UIN as the sole user identifier.

Data protection

The amalgamated, password protected, anonymised database was stored on MJG's computer. No one else had access to the computer or its passwords. All data is anonymised and the unique identifier will be an ID given to participants. The data will be stored in encrypted form and in a locked office.

Statistical Analysis

All analyses were performed using R, version 2.15.2 (R Foundation for Statistical Computing, http://www.rproject.org). Each of the VR measures were individually analysed with respect to the ASAT measures using Pearson's correlation coefficients. A priori power analysis showed a total sample size of 33 subjects would be sufficiently powered to show a significant correlation, assuming an r^2 value of at least 0.2, a significance level of 0.05, and a power of 80%. Assuming 15% attrition of subjects during the study, a target total sample size of 38 subjects was deemed sufficient.

Chapter 4: Results

All 49 participants met the eligibility criteria and completed the study session successfully. The raw data collected is presented in the Appendix.

Basic demographics of participants taking part is summarised in Table 10 below.

Mean age	21.6 years (+/- 2.2 years)
Male : Female	32 : 17 (65.3% : 34.7%)
Left : Right hand dominance	1 : 46 (2% : 93.9%) [* 2 ambidextrous]

Table 10: Basic demographics of participants.

Tables 11 through to Table 14 show the correlations between the ASATs measures (row headers) and the VR measures (column headers) for the VR tasks "*operating room*", "*palpate*", "*visualise*" and "*pendulum*" respectively.

A p value < 0.05 suggests that the correlation observed reached significance. Pearson correlation (r) shows the type of correlation:

- r = a positive value suggests the 2 measures have a positive correlation (an increase in one measure would increase the other measure).
- r = a negative value suggests the 2 measures have a negative correlation (an increase in one measure would decrease the other measure).

The r value range is from +1 to -1, with +1 being the strongest positive correlation, 0 being no correlation and -1 being the strongest negative correlation. The 95% confidence intervals are given alongside the Pearson's correlation in parenthesis.

An overview of all the results shows that for:

- *Operating Room* VR task, 16 correlations were analysed.
- *Palpate* VR task 40 correlations were analysed.
- *Visualise* VR task 24 correlations were analysed.
- *Pendulum* VR task 40 correlation were analysed.

Operating Room VR task

7/16 (44%) correlations achieved significance (table cells highlighted in yellow), with camera covered distance (VR motion analysis) showing the strongest correlations (the r values being further away from 0). The motion analysis in the ASATs (delta distance) correlated the strongest with the camera covered distance suggested the motion analysis parameter in both systems shows concurrent validity.

Palpate VR task

12/40 (30%) correlations achieved significance (table cells highlighted in yellow), with the VR time-based and distance-based (motion analysis) measures showing the strongest correlations with ASATs time-based and distance-based measures. This suggests the time-based and motion analysis parameters in both systems shows concurrent validity.

Errors-based measures (out-number) in the ASATs showed a significant but weaker correlation with the VR time and distance-based measures The error-based measure on the VR is a measure of roughness (haptic feedback). No haptic feedback is present on the ASATs. It is not surprising that no ASAT measures correlated with the VR error-based measures. This suggests that the ASATs measure of errors does not concur in measuring errors in the same way as the VR for this task. The ASATs does however predict that those making these errors will take a longer time and have a more hand movement (motion analysis).

Visualise VR task

9/24 (38%) correlations achieved significance (table cells highlighted in yellow), with the VR time-based and distance-based (motion analysis) measures showing the strongest correlations with ASATs time-based and distance based measures. This suggests the time-based and motion analysis parameters in both systems shows concurrent validity.

Errors-based measures (out-number and drop times) in the ASATs showed a significant but weaker correlation with the VR time and distance based measures. Again, it is not surprising that no ASAT measures correlated with the VR error-based measures. This suggests that the ASATs measure of errors does not concur in measuring errors in the same way as the VR for this task. Again, the ASATs does however predict that those making these errors will take a longer time and have a more hand movement (motion analysis).

Pendulum VR task

17/40 (43%) correlations achieved significance (table cells highlighted in yellow), with yet again the VR time-based and distance-based (motion analysis) measures showing the strongest correlations with ASATs time-based and distance based measures. This suggests the time-based and motion analysis parameters in both systems shows concurrent validity.

Errors-based measures (out-number and drop times) in the ASATs showed a significant but weaker correlation with the VR time and distance based measures. Errors-based measures (out-time and on work) showed a significant but weaker correlation with the VR error-based measures (probe roughness). This suggests that the ASATs measure of errors does not concur in measuring errors in the same way as the VR for this task. Again, the ASATs does predict that those making these errors will take a longer time and have a more hand movement (motion analysis). The weak, but significant correlation between ASATs out-time and on-work with VR probe roughness will need further investigation as this was not observed in any other VR task.

ASATs outcome measures

Comparing like-to-like (i.e.ASATs time-based with VR time-based, distance-based with distance-based and errors-based with error-based), the ASATs outcome measures which had the best correlation with same category of VR assessment were:

1. Distance-based (delta distance and distance total) with VR camera and instrument covered distance 12/12 (100%).
2. Time-based with VR time taken in 3/4 (75%) the VR tasks: *visualise* ($r = 0.381$, $p = 0.007$), *locate and palpate* ($r = 0.596$, $p < 0.001$), and *pendulum* ($r = 0.646$, $p < 0.001$).

Error-based measures on the ASATs (out-time, out-number, on-box, on-work, drop times) significantly correlated with VR error-based measures (camera roughness and instrument roughness) on 16 occasions out of 55 analyses (29%). Out of the 16 significant correlations, 8 of them were "out-number". Specifically looking at this ASAT outcome measure, "out-number" did not significantly correlate with any VR error-based measure. It correlated on 8 occasions out of 10 for either time- or distance-based VR parameters. This raises the possibility that even though the "out-number" was designed to be an ASAT error-based performance parameter, it actually was much better performing as a predictor of performance of VR time- and distance-based measures. In other words, the higher the out-number in the ASATs (the more times you have out of the working area), the longer the time you will take to complete the VR task and also the motion path will be longer on the VR. This is an indirect measure that the user did not perform the task with well controlled movement.

	Time	Camera Cov Dist
Time Taken	p = 0.114 r = 0.229 (-0.056, 0.479)	p = 0.144 r = 0.212 (-0.074, 0.465)
Out Time	p = 0.214 r = 0.181 (-0.106, 0.440)	p = 0.044 r = 0.289 (0.008, 0.527)
Out Number	p = 0.259 r = 0.164 (-0.123, 0.426)	p = 0.047 r = 0.285 (0.004, 0.524)
On Box	p = 0.788 r = -0.040 (-0.317, 0.244)	p = 0.369 r = -0.131 (-0.398, 0.156)
On Work	p = 0.214 r = -0.181 (-0.440, 0.106)	p = 0.044 r = -0.289 (-0.527, -0.008)
Drop Times	p = 0.115 r = 0.228 (-0.057, 0.478)	p = 0.225 r = 0.177 (-0.110, 0.436)
Distance Total	p = 0.015 r = 0.347 (0.073, 0.572)	p = 0.003 r = 0.417 (0.154, 0.625)
Delta Distance	p = 0.014 r = 0.351 (0.077, 0.575)	p = 0.003 r = 0.421 (0.159, 0.628)

Table 11: Summary of correlations between the "shape match with inverted controls" ASAT and the "operating room" VR task. Cov Dist = Covered Distance.

	Time	Camera Cov Dist	Camera Roughness	Probe Cov Dist	Probe Roughness
Time Taken	$p < 0.001$ $r = 0.595$ (0.377, 0.751)	$p < 0.001$ $r = 0.571$ (0.344, 0.734)	$p = 0.073$ $r = 0.259$ (-0.024, 0.503)	$p < 0.001$ $r = 0.634$ (0.429, 0.777)	$p = 0.046$ $r = 0.286$ (0.006, 0.525)
Out Time	$p = 0.149$ $r = 0.209$ (-0.077, 0.463)	$p = 0.079$ $r = 0.253$ (-0.030, 0.499)	$p = 0.289$ $r = -0.155$ (-0.418, 0.132)	$p = 0.288$ $r = 0.155$ (-0.132, 0.418)	$p = 0.463$ $r = -0.107$ (-0.377, 0.179)
Out Number	$p = 0.005$ $r = 0.392$ (0.125, 0.607)	$p < 0.001$ $r = 0.465$ (0.212, 0.660)	$p = 0.909$ $r = -0.017$ (-0.297, 0.266)	$p = 0.019$ $r = 0.334$ (0.058, 0.562)	$p = 0.777$ $r = 0.042$ (-0.243, 0.320)
On Box	$p = 0.738$ $r = 0.050$ (-0.235, 0.326)	$p = 0.844$ $r = 0.029$ (-0.254, 0.308)	$p = 0.121$ $r = 0.224$ (-0.061, 0.476)	$p = 0.825$ $r = -0.033$ (-0.311, 0.251)	$p = 0.164$ $r = 0.202$ (-0.084, 0.457)
On Work	$p = 0.149$ $r = -0.209$ (-0.463, 0.077)	$p = 0.079$ $r = -0.253$ (-0.500, 0.030)	$p = 0.289$ $r = 0.155$ (-0.132, 0.418)	$p = 0.288$ $r = -0.155$ (-0.418, 0.132	$p = 0.463$ $r = 0.107$ (-0.179, 0.377)
Drop Times	$p = 0.104$ $r = 0.235$ (-0.050, 0.484)	$p = 0.126$ $r = 0.221$ (-0.064, 0.473)	$p = 0.403$ $r = 0.122$ (-0.165, 0.390)	$p = 0.064$ $r = 0.267$ (-0.015, 0.510)	$p = 0.996$ $r = 0.001$ (-0.281, 0.282)
Distance Total	$p < 0.001$ $r = 0.650$ (0.450, 0.787)	$p < 0.001$ $r = 0.666$ (0.473, 0.798)	$p = 0.989$ $r = -0.002$ (-0.283, 0.279)	$p < 0.001$ $r = 0.663$ (0.469, 0.796)	$p = 0.354$ $r = 0.135$ (-0.152, 0.401)
Delta Distance	$p < 0.001$ $r = 0.652$	$p < 0.001$ $r = 0.667$	$p = 0.996$ $r = 0.001$	$p < 0.001$ $r = 0.664$	$p = 0.339$ $r = 0.140$

	(0.453, 0.788)	(0.475, 0.798)	(-0.281, 0.282)	(0.471, 0.797)	(-0.148, 0.405)

Table 12: Summary of correlations between the "shape match with inverted controls" ASAT and the "Palpate" VR task. Cov Dist = Covered Distance.

	Time	Camera Cov Dist	Camera Roughness
Time Taken	p = 0.007 r = 0.381 (0.112, 0.598)	p = 0.003 r = 0.413 (0.150, 0.622)	p = 0.121 r =0.224 (-0.061, 0.476)
Out Time	p = 0.150 r = 0.209 (-0.077, 0.463)	p = 0.329 r = 0.143 (-0.145, 0.407)	p = 0.966 r = -0.006 (-0.287, 0.275)
Out Number	p = 0.088 r = 0.246 (-0.037, 0.493)	p = 0.092 r = 0.243 (-0.041, 0.491)	p = 0.196 r = 0.188 (-0.099, 0.446)
On Box	p = 0.150 r = -0.209 (-0.463, 0.077)	p = 0.085 r = -0.249 (-0.495, 0.035)	p = 0.661 r = 0.064 (-0.221, 0.339)
On Work	p = 0.150 r =-0.209 (-0.463, 0.077)	p = 0.329 r =-0.143 (-0.407, 0.145)	p = 0.966 r = 0.006 (-0.275, 0.287)
Drop Times	p = 0.039 r = 0.296 (0.0157, 0.533)	p = 0.047 r = 0.286 (0.005, 0.525)	p = 0.158 r = 0.205 (-0.081, 0.460)
Distance Total	p = 0.003 r = 0.411 (0.146, 0.620)	p = 0.005 r = 0.396 (0.129, 0.609)	p = 0.245 r = 0.170 (-0.117, 0.430)
Delta Distance	p = 0.003 r = 0.415 (0.152, 0.624)	p = 0.004 r = 0.400 (0.134, 0.612)	p = 0.240 r = 0.171 (-0.116, 0.432)

Table 13: Summary of correlations between the "shape match with inverted controls" ASAT and the "Visualise" VR task. Cov Dist = Covered Distance.

	Time	Camera Cov Dist	Camera Roughness	Probe Cov Dist	Probe Roughness
Time Taken	p < 0.001 r = 0.646 (0.446, 0.785)	p < 0.001 r = 0.663 (0.470, 0.796)	p = 0.552 r = 0.087 (-0.199, 0.360)	p < 0.001 r = 0.660 (0.465, 0.794)	p = 0.113 r = 0.229 (-0.056, 0.480)
Out Time	p = 0.164 r = 0.202 (-0.084, 0.457)	p = 0.152 r = 0.208 (-0.078, 0.462)	p = 0.349 r = 0.137 (-0.150, 0.403)	p = 0.416 r = 0.119 (-0.168, 0.387)	p = 0.041 r = 0.293 (0.013, 0.531)
Out Number	p = 0.008 r =0.378 (0.108, 0.596)	p = 0.012 r = 0.356 (0.082, 0.579)	p = 0.420 r = 0.118 (-0.169, 0.386)	p = 0.042 r = 0.292 (0.012, 0.530)	p = 0.071 r = 0.260 (-0.023, 0.504)
On Box	p = 0.476 r = 0.104 (-0.182, 0.375)	p = 0.560 r = 0.085 (-0.201, 0.358)	p = 0.970 r = -0.005 (-0.286, 0.276)	p = 0.429 r = 0.116 (-0.171, 0.384)	p = 0.803 r = -0.037 (-0.315, 0.247)
On Work	p = 0.164 r = -0.202 (-0.457, 0.084)	p = 0.152 r = -0.208 (-0.462, 0.078)	p = 0.349 r = -0.137 (-0.403, 0.150)	p = 0.416 r = -0.119 (-0.387, 0.168)	p = 0.041 r =-0.293 (-0.531, - 0.013)
Drop Times	p = 0.003 r = 0.415 (0.152, 0.623)	p < 0.001 r = 0.5403 (0.306, 0.713)	p = 0.539 r = -0.090 (-0.362, 0.196)	p < 0.001 r = 0.484 (0.234, 0.673)	p = 0.597 r = 0.077 (-0.208, 0.351)
Distance Total	p < 0.001 r = 0.613 (0.401, 0.763)	p < 0.001 r = 0.540 (0.306, 0.713)	p = 0.340 r =0.139 (-0.148, 0.405)	p < 0.001 r = 0.538 (0.302, 0.712)	p = 0.063 r = 0.268 (-0.015, 0.510)
Delta Distance	p < 0.001 r = 0.615	p < 0.001 r = 0.538	p = 0.318 r = 0.146	p < 0.001 r = 0.539	p = 0.064 r = 0.267

	(0.404, 0.764)	(0.302, 0.711)	(-0.141, 0.410)	(0.304, 0.713)	(-0.019, 0.510)

Table 14: Summary of correlations between the "shape match with inverted controls" ASAT and the "Pendulum" VR task. Cov Dist = Covered Distance.

Based on the thesis aims, the table of correlation can be summarised as below:

	Performance measures on		Correlation
	ASATs	VR	
Time-based	Time taken	Time taken	75% +
Distance-based	Distance total Distance total	Camera Covered distance Probe covered distance	100% +
	Delta distance Delta distance	Camera Covered distance Probe covered distance	100% +
Error-based	Out-time Out-time	Camera roughness Probe roughness	17%
	Out-number Out-number	Camera roughness Probe roughness	0%
	On-box On-box	Camera roughness Probe roughness	0%
	On-work On-work	Camera roughness Probe roughness	17%
	Drop times Drop times	Camera roughness Probe roughness	0%

Table 15: Observed correlations between the "shape match with inverted controls" ASAT and VR tasks.

This suggests that the ASATs has concurrent validity for time-based and distanced-based performance parameters. This is strengthened by the addition of "out-number" which was originally designed as a "error-based" parameter.

An updated table of correlation taking into account this change of parameter purpose, the following is observed:

	Performance measures on		Correlation
	ASATs	**VR**	
Time-based	Time taken	Time taken	75% +
	Out-number	Time taken	75% +
Distance-based	Distance total Distance total	Camera Covered distance Probe covered distance	100% +
	Delta distance Delta distance	Camera Covered distance Probe covered distance	17%
	Out-number Out-number	Camera Covered distance Probe covered distance	83% +
Error-based	Out-time Out-time	Camera roughness Probe roughness	17%
	On-box On-box	Camera roughness Probe roughness	0%
	On-work On-work	Camera roughness Probe roughness	17%
	Drop times Drop times	Camera roughness Probe roughness	0%

Table 16: Observed correlations between the "shape match with inverted controls" ASAT and VR tasks with re-classification of the ASAT "out-number" performance measure to a distance-based measure (table cells labelled yellow).

Chapter 5: Discussion

The ASATs were designed to be widely accessible and low cost simulation tools. The system provides time-, motion- and error-based objective feedback on complex hand-eye coordination tasks. Inverted controls were implemented in ASATS to match the type of hand-eye coordination skills required for arthroscopy. The "shape match" ASAT requires the picking up, moving, and releasing of a shape and therefore shares procedural skills with removal of a loose body or manipulation of tissues or sutures within the joint during real life arthroscopy. The relevance of both of these tasks to real world arthroscopy was the reason for the selection of "shape match with inverted controls" for the main study, described in Chapter Three.

The results from this study show that performance on the "shape match with inverted controls" ASAT correlates with performance on the Insight Arthro VR on multiple measures. Specifically, statistically significant and moderate strength correlations were observed between performance on the VR and on the ASAT for both time-based and distance-based parameters. It is well established that speed of movement is one measure of skill in complex hand-eye coordination tasks[149] and hence it is unsurprising that participants who were faster on the tasks in VR also tended to perform the "shape match with inverted controls" tasks on ASAT faster. However, accuracy of movement is also a measure of skill in complex hand-eye coordination tasks. In a review of arthroscopy simulators and their ability to assess arthroscopic skills, Modi et al. [143] reported that the time to task completion, distance travelled by the probe, and the path taken by probe best discriminate the skill of the operator[143]. This finding is of real world relevance, as the arthroscopic surgeon is operating in a very confined space, where risk of iatrogenic damage may be associated with excessive movements of the camera and tools. Therefore, it is also encouraging that the distance-based performance measures in ASATs correlated well with the equivalent measure in VR.

As the Insight Arthro VR has been shown to have construct and transfer validity[70] this suggests that the "shape match with inverted controls" ASAT, by showing concurrent validity, may help individuals develop core skills for shoulder arthroscopy via this online, widely accessible system.

The error-based parameters did not show concurrent validity between the systems. This is largely due to the key difference between the input devices on the ASATs and the VR simulator. The ASATs uses a mouse and keyboard, neither of which provide haptic feedback to the user.

In contrast, the VR uses robotic arms designed to provide haptic feedback to the user in the form of the tactile feeling of "hitting" or "colliding" with objects. This can be desirable when trying to triangulate multiple instruments, or be detrimental when colliding with the articular surface within the simulated joint; either way, it provides users with an extra sensory modality. It is therefore unsurprising that there was minimal correlation between any of the ASAT measures and the VR measure of roughness, which is based on haptic feedback.

The need for haptic feedback may not be as important as envisaged; in one Dutch survey, tactile sensation was rated "not important" by both senior and junior surgeons,[150,151] and no studies have demonstrated superiority of haptic simulators over non-haptic ones[53]. However, it would be interesting to investigate if another sensory modality, such as sound, gives users useful feedback in the absence of haptic feedback.

Relevance for training

The exact protocol for use of simulation systems in training programmes and beyond requires further study, and surgical training programmes will need to adapt to accommodate the emergence of simulation. Brydges et al. [152] reported that progression of training through simulators of increasing fidelity leads to superior transfer of a broad range of clinical skills. They suggested that clinical training curricula should incorporate exposure to multiple simulators to maximise educational benefit and potentially save educator time[152]. Specific to motor skills, Shmuelof et al. proposed that skills acquisition can be characterised by a reduction on movement variability (i.e. reduction in attempt-to-attempt variability and an increase in movement smoothness)[149].

MJG believes that a combination of increasing fidelity simulator exposure and feedback to the trainee to reduce the overall movement variability may lead to the optimum skills transfer. MJG proposes a linear 4-stage approach to arthroscopic skills. This utilises low-fidelity simulators in the early stages and higher fidelity systems in the latter stages.

In the first stage (cognitive), trainees develop a general understanding of arthroscopy and its equipment, particularly inverted hand-eye coordination and optimising camera viewing. The fibre-optic camera image is displayed on a screen away from the surgical site and the trainee's hands are often at an offset angle; it is thus imperative that trainees can match their visual and proprioceptive senses. The proprioceptive senses need to take the fulcrum effect the body has on the instruments into account, thereby causing inverted movements.

The second stage (core skills acquisition) is fundamentally about acquiring and mastering inverted hand-eye coordination skills. These skills do not need to be learned in an anatomically accurate environment, but they do need to be task-driven and objective parameters measured with feedback given. This task should be fully understood so that there is minimal familiarisation time when the inverted procedural skills are being practised. This is the stage where the ASATs can help in the absence of more expensive simulators and may help select those trainees who are ready to progress to Stage 3.

The third stage (procedural skills training) involves the development of more advanced arthroscopic skills for specific tasks or procedures commonly encountered during arthroscopy, e.g. probing articular surfaces, assessing the labrum, or inserting bony anchors. This stage is best mastered using more expensive simulators, such as VR or cadaveric, with better face validity.

These three stages can help advance a trainee's learning curve prior to developing their intra-operative skills on a real patient. Stage 4 (skills transference) utilises these learned skills that have been developed in a safe environment and transfers them into the operating theatre. Identification of structures and navigation skills are regarded as highly important to trainees prior to operating on patients[150,151].

Development Costs

The barriers of setting up stage two training tools, such as ASATs, include the conversion of the prototype research tool into a user-friendly tool for real-life training and the collection of sufficient data to allow meaningful feedback to users about their performance relative to others (either expert arthroscopy surgeons or those at a similar stage of training and experience). Online instructional material or interactive sessions with trainers and trainees are probably required, which may add to set-up costs. However, it is possible for multiple institutions to share development, start up, and maintenance costs when the resource is online and centralised.

Limitations

The face validity of this prototype will never achieve the same levels as a VR simulator; this is a conscious decision designed to cut costs and improve accessibility by utilising commonly available input devices and software. However, this simulation tool has the potential to provide additional information and assessment, most likely before or in the early stages of training, and at virtually no cost to the end user. Also, users in this study performed the ASATs tasks followed by the VR tasks. This may have allowed the inverted hand-eye coordination skills to improve prior to learning the latter tasks. Arthroscopic instruments typically use a 30° scope to optimise the light source for visualisation within a joint. The next version of the ASATs hopes to simulate this by using the central mouse wheel as a light source control.

Future work

It is unclear whether ASATs can help develop skills in individuals who do not show baseline aptitude for simulated arthroscopy. To address this, a study is required to investigate the learning curve for both VR and the ASATs independently and longitudinally. Additionally, it would be important to understand how these two techniques interact and can be used together. Correlation studies, such as the one presented here, help us to focus on the ASAT's measures that are most likely to be useful for training and require optimisation and subsequent validation.

This study shows the "shape match with inverted controls" ASAT positively correlates with a validated arthroscopic VR simulator, but it does not validate ASAT performance as a measure of arthroscopic competence; it is not possible to display a "pass score" to indicate successful acquisition of core arthroscopic skills. A construct validation study is required to investigate the ability of the ASATs to differentiate between an expert group performance and a novice group.

Further development and investigations will need to be done regarding developing the ASATs method of measuring errors. The current parameters designed to measure errors did not correlate with the VR error-based measures of camera or probe roughness. The use of another sensory modality, such as sound, instead of or in conjunction with visual feedback will need to be investigated. The alternative of investing in hardware would go against the cheap and widely accessible ethos of the ASATs. If no other modality or method of representing errors is found to correlate with haptic feedback, it may then drive the need for the ASATs to offer additional haptic feedback through an optional hardware peripheral unit with minimal investment.

Conclusion

This thesis has introduced a novel computer-based tool, ASATS, which shows potential for use in the training and/or assessment of arthroscopy surgery skills. The study compared performance on the "Shape Match with Inverted Controls" ASAT and task performance on a validated arthroscopic VR simulator. Significant and moderate strength correlations were found between time- and motion-based performance measures and hence, for these performance measures, the ASAT has achieved concurrent validity whilst maintaining its aims of being widely accessible and low cost. The findings suggest there may be merit in further development of the ASATs, as well as future studies to explore how it could best be used in future surgical training programmes.

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Appendices

Note: A shared application was made between the ASATs study and the eye-tracking study for ethical, organisational and sponsor approval. Similarly, recruitment was shared between the studies. This thesis refers only to the ASATs. The eye-tracking study was investigated by Mr Mike Anderton.

Ethical, Organisational and Sponsor Approvals

University of Salford
MANCHESTER

Research, Innovation and Academic Engagement Ethical Approval Panel

College of Health & Social Care
AD 101 Allerton Building
University of Salford
M6 6PU

T +44(0)161 295 7016
r.shuttleworth@salford.ac.uk

www.salford.ac.uk/

19 November 2012

Dear Maulik,

RE: ETHICS APPLICATION HSCR12/67 – Validation of Arthroscopic Skills Acquisition Tools (ASATs) and Assessment of Eye Tracking in Simulated Shoulder Arthroscopy.

Following your responses to the Panel's queries, based on the information you provided, I am pleased to inform you that application HSCR12/67 has now been approved.

If there are any changes to the project and/ or its methodology, please inform the Panel as soon as possible.

Yours sincerely,

Rachel Shuttleworth

Rachel Shuttleworth
College Support Officer (R&I)

NHS
North of England

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3rd Floor
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Fax: 0161 625 7503
http://www.nwpgmd.nhs.uk

Dr MJ Anderton
36 Ladythorn Road
Bramhall
Stockport
SK7 2ER

17th September 2012

Dear Dr Anderton,

Re: Validation of arthroscopic skills acquisition tools (ASATs) & assessment of eye tracking in simulated shoulder arthroscopy study.

I write to confirm that your application for organisational approval by NHS North of England, and Sponsor's approval by the North Western Deanery, to conduct the above research study has been approved.

You may now proceed with the research.

Yours sincerely

Dr Steven J Agius
Senior Research Fellow in Medical Education
North Western Deanery

NHS North East, NHS North West and NHS Yorkshire and the Humber - the three strategic health authorities in the North of England - now work together under a single management framework as NHS North of England.

Participant Information Sheet (detailed)

PROJECT TITLE: Validation of Arthroscopic Skills Acquisitions Tools (ASATs) for Shoulder Arthroscopy and Assessment of Eye Tracking in Simulated Shoulder Arthroscopy.

Dear Participant,

Many thanks for your interest in this research study. This study is open to medical students who do not have any experience in PERFORMING keyhole surgery, although it is ok if you have watched and understand how keyhole surgery works. In addition, the study will involve input from Consultant Orthopaedic Shoulder Surgeons.

Arthroscopy (key hole surgery into a joint) is difficult to master because it requires advanced hand-eye coordination skills. These skills can be developed, but each person has their own learning curve. This study is looking at ways of improving or speeding up this learning curve.

This research project is broadly looking at 2 hypotheses:

Whether the skills required for arthroscopic surgery can be acquired or developed with regular hand-eye coordination tasks. These tasks are performed on a computer using a keyboard and mouse (ASATs).

Whether eye movements correlate with arthroscopic performance, and if there is a difference between novice and expert participants. If a difference exists, we would be interested in seeing what these differences were and whether eye movements can be trained to help accelerate their learning curves.

To test these hypotheses, participants will be asked to complete the ASATs tasks and the virtual reality simulator tasks. There are 6 ASATs tasks, 4 virtual reality simulator tasks and 3 synthetic shoulder simulator tasks. These are described in further detail below. A video will also be shown to demonstrate the ASATs on the day.

To test the eye movements, an eye-tracking device will be placed on a spectacles frame that you have to wear for the device to work. These spectacles fit over any corrective glasses you may already be wearing. If you do not wish to wear the eye tracking spectacles or they are uncomfortable, then you can be excluded from this part of the study. You can still continue with the rest of the study.

On your first visit, you will be allocated a group, which will determine if you have access to the ASATs outside the study visits. The ASATs will record your scores, and how often you have utilised access to these tools. You will have 7 visits scheduled; one for baseline performance and 6 follow up visits (monthly intervals) to assess your learning curve. A flow diagram outlining the course of the study is shown below.

You are free to withdraw from the study at any time.

Taking part or opting out of the study will not influence your present or future medical training.

You will be given a certificate of participation in this study. You may already know that virtual reality simulators are very expensive training tools, but as a participant you will have supervised access to them for free. You will also have access to the ASATs after the study has finished.

There is no financial reward for taking part in this study.

All data obtained from this study will be used anonymously for poster, podium and paper presentations.

Should you have any questions at any stage, please contact Mr Maulik J Gandhi (07868 657 362, maulikjgandhi@yahoo.co.uk). Remember, you are free to withdraw from the study at any stage.

Many thanks for your interest and help,

Yours Sincerely

Mr Maulik J Gandhi, Mr Michael Anderton, Prof Len Funk, Prof D Roberts, Prof P Turner

Participant Information Sheet (overview)

PROJECT TITLE: Validation of Arthroscopic Skills Acquisitions Tools (ASATs) for Shoulder Arthroscopy and Assessment of Eye Tracking in Simulated Shoulder Arthroscopy.

Dear Participant,

Many thanks for your interest in this research study. This study is looking at ways of improving or speeding up the learning curve for keyhole surgery. It is open to medical students who do not have any experience in PERFORMING keyhole surgery, although it is ok if you have watched and understand how it works.

The study has 2 parts:

For assessment on the ASATs, you will be required to use a computer and mouse. On your first visit, you will be allocated into one of two groups. This will determine if you have access to the ASATs outside the study visits. A flow diagram explaining the study is shown below. The ASATs will record your scores, and how often you have used these tools.

To test eye movements, an eye-tracking device will be placed on a spectacles frame that you have to wear for the device to work. These spectacles fit over any corrective glasses you may already be wearing. If you do not wish to wear the eye tracking spectacles or they are uncomfortable, you can be excluded from this part of the study. You can still continue with the rest of the study.

You will also be assessed on a virtual reality simulator. You may already know that virtual reality simulators are very expensive training tools, but as a participant you will have supervised access to them for free. You will also have access to the ASATs after the study has finished.

You are free to withdraw from the study at any time and taking part or opting out of the study will not influence your present or future medical training.

All information obtained from this study will be used anonymously for poster, podium and paper presentations.

Should you have any questions at any stage, please contact Mr Maulik J Gandhi (07868 657 362, maulikjgandhi@yahoo.co.uk). Remember, you are free to withdraw from the study at any stage.

Many thanks for your interest and help,

Yours Sincerely

Mr Maulik J Gandhi, Mr Michael Anderton, Prof Len Funk, Prof D Roberts, Prof P Turner

Title: Click Points

Objective: move the mouse pointer over the static point, and left click (in one hand mode) or spacebar press (in two hand mode)

Positive scoring factors: keeping the pointer in the white area, not hitting the obstructions (red), quickly click all the points, accurate and steady movements.

Negative scoring factors: hitting the obstructions, moving out of the white area into the grey area, taking a long time to click all the points, wild and rash movements.

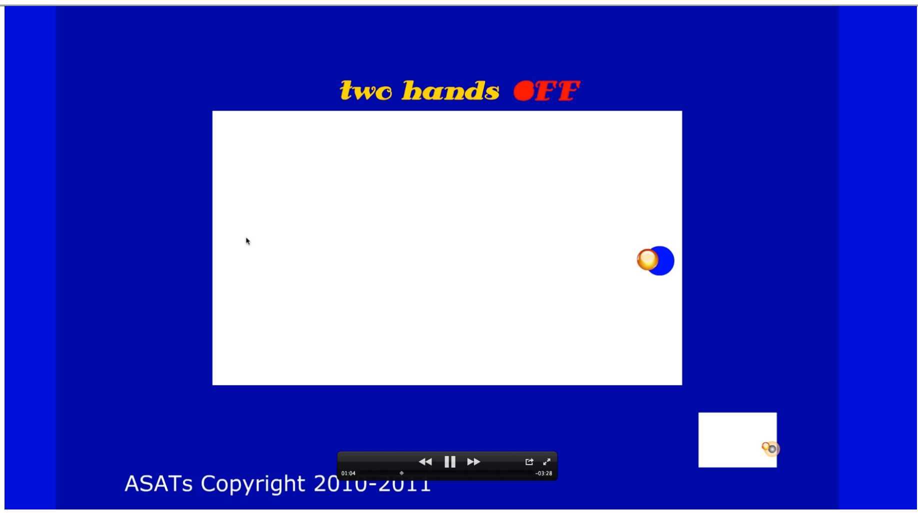
Title: Click Points with Inverted Controls

Objective: move the mouse pointer over the static point, and left click (in one hand mode) or spacebar press (in two hand mode)

Positive scoring factors: keeping the pointer in the white area, not hitting the obstructions (red), quickly click all the points, accurate and steady movements.

Negative scoring factors: hitting the obstructions, moving out of the white area into the grey area, taking a long time to click all the points, wild and rash movements.

Hand movement	Screen movement
Up	down
Down	up
Left	right
Right	left



Title: Track Box

Objective: keep the mouse pointer over the tracking box

Positive scoring factors: keeping the pointer in the white area, not hitting the obstructions (red), keeping the pointer over the moving box, accurate and steady movements.

Negative scoring factors: hitting the obstructions, moving out of the white area into the grey area, wild and rash movements.

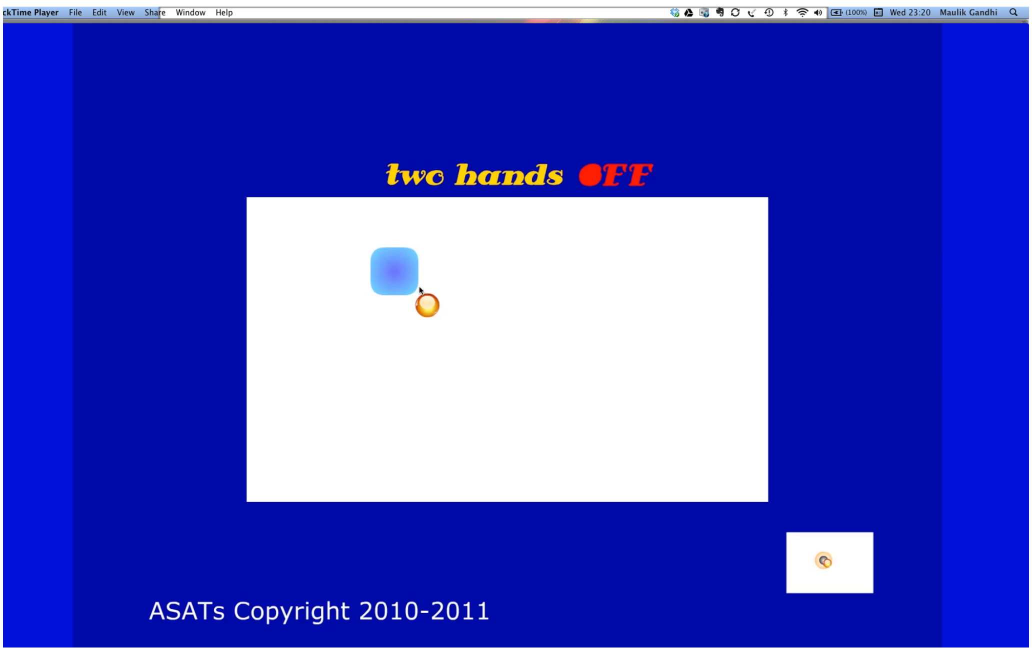
Title: Track Box with Inverted Controls

Objective: keep the mouse pointer over the tracking box

Positive scoring factors: keeping the pointer in the white area, not hitting the obstructions (red), keeping the pointer over the moving box, accurate and steady movements.

Negative scoring factors: hitting the obstructions, moving out of the white area into the grey area, wild and rash movements.

Hand movement	Screen movement
Up	down
Down	up
Left	right
Right	left



Title: Shape Match

Objective: move the mouse pointer over the static blue shape, and left click (in one hand mode) or spacebar press once to hold, and press 2nd time to release (in two hand mode) into the corresponding grey shape

Positive scoring factors: keeping the pointer in the white area, not hitting the obstructions (red), quickly dropping all the shapes into the corresponding shapes, accurate and steady movements, not losing the pointer out of the scope view (in two hand mode) as this will drop the shape.

Negative scoring factors: hitting the obstructions, moving out of the white area into the grey area, taking a long time to drop.

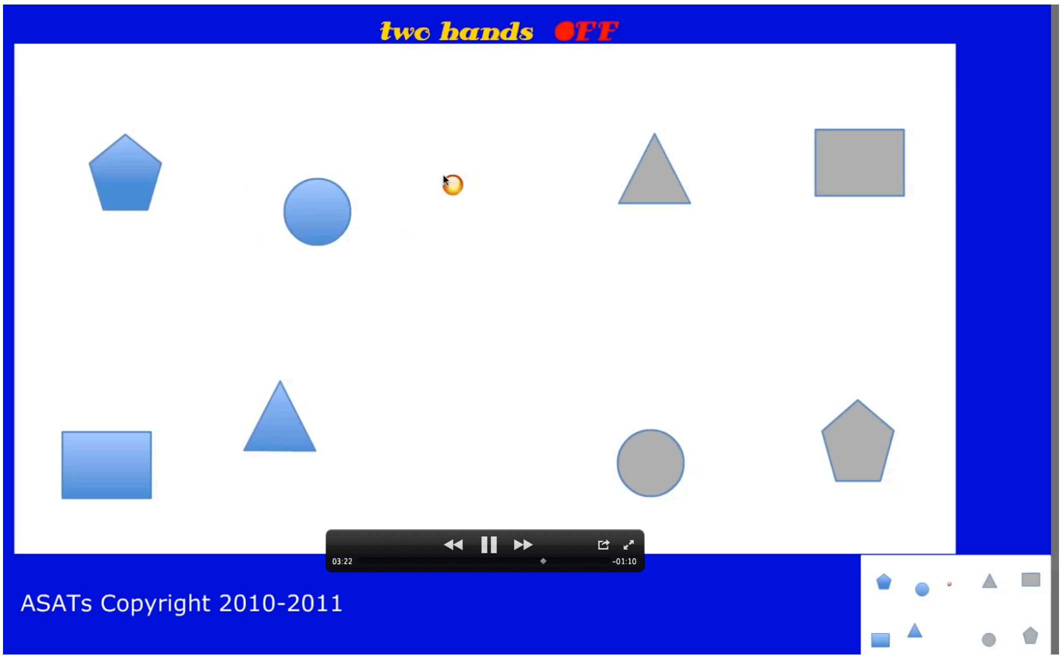
Title: Shape Match with Inverted Controls

Objective: move the mouse pointer over the static blue shape, and left click (in one hand mode) or spacebar press once to hold, and press 2nd time to release (in two hand mode) into the corresponding grey shape.

Positive scoring factors: keeping the pointer in the white area, not hitting the obstructions (red), quickly dropping all the shapes into the corresponding shapes, accurate and steady movements, not losing the pointer out of the scope view (in two hand mode) as this will drop the shape

Negative scoring factors: hitting the obstructions, moving out of the white area into the grey area, taking a long time to drop the shapes into the corresponding shapes, wild and rash movements.

Hand movement	Screen movement
Up	down
Down	up
Left	right
Right	left


two hands OFF
03:22
-01:10
ASATs Copyright 2010-2011

Virtual reality simulator tasks

1. operating room (familiarisation) – you need to focus the scope view onto the bull's eye target. The target will turn yellow when focussed, and this needs to be held for 3 consecutive seconds. You then move onto the next bull's eye target.

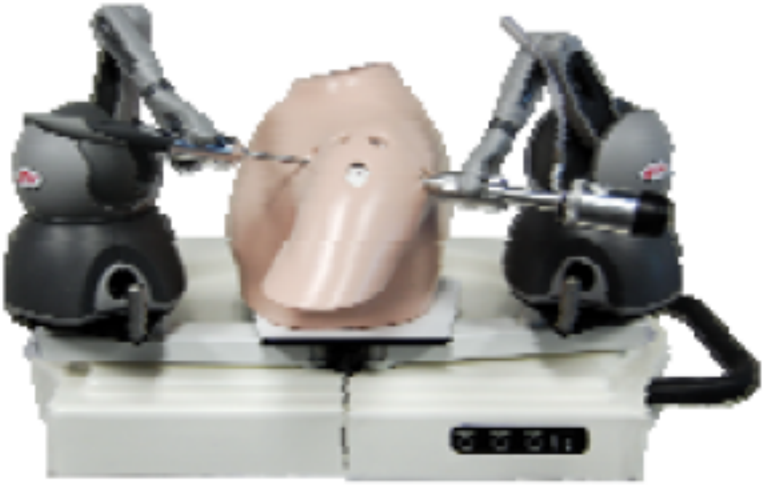
2. locate and palpate (anatomical) (two hand) – you need to focus on the ball (which will turn blue when focussed) for 3 consecutive seconds. Once this has been completed, the ball needs to be probed (touched) with the instrument in the other hand. This will turn the ball blue and this needs to be held for 3 seconds. You then move onto the next ball.

3. visual examination (anatomical) (one hand) – you need to focus on the ball (which will turn blue when focussed) for 3 consecutive seconds. You then move onto the next ball.

4. pendulum (non-anatomical) (two hand) – you need to touch the moving ball (which will turn blue) for 5 consecutive seconds. The ball will then move in a different direction. You have to touch it for 5 consecutive seconds.

Anatomical Landmarks used

1. biceps tendon
2. posterior labrum
3. inferior labrum
4. centre of glenoid
5. supraspinatus insertion
6. denuded cartilage
7. humeral cartilage
8. subscapularis
9. medial glenohumeral ligament
10. inferior glenohumeral ligament



Participant Consent Form

PROJECT TITLE: Validation of Arthroscopic Skills Acquisitions Tools (ASATs) for Shoulder Arthroscopy and Assessment of Eye Tracking in Simulated Shoulder Arthroscopy.

Please initial each statement to indicate you agree to the statement

I agree:

The project has been explained	
There has been an opportunity to ask questions	
Photos and videos can be taken as long as I cannot be identified	
Data collected during this project can be presented in a non-identifiable format	
No financial incentive has been/will be given for participation	
To participate out of my own free will and understand that I can withdraw at any stage	

Participant Name:____

Participant Signature:____

Date:____

Participant Advert Material developed with Scalpel Surgical Society

Subject: surgical simulator training study!

Background:

Training in the UK has changed since the European Working Time Directive, resulting in less training time. This means less opportunity to develop surgical skills. We have looked at ways of developing these skills, and one way is through the use of simulators. The current simulators are expensive, and also not very accessible. During this study we will also look at eye tracking, which is an essential part of hand/eye co-ordination, but often overlooked. Eye tracking will be recorded during use of the virtual reality simulator and results of medical students will be compared to orthopaedic consultants.

Project objective 1:

This will look at 3 different simulators and see whether they help to develop arthroscopic surgical skills (keyhole surgery into a shoulder joint).

Simulator 1: Virtual reality simulator

Simulator 2: Plastic model simulator

Simulator 3: Computer model simulator

Hypotheses: regular simulator training, irregardless of which simulator is used, will develop arthroscopic skills.

Methods: 100 medical students will be recruited. 2 groups will be formed - 3SIM access and 2SIM access. 3SIM access will have access to 3 simulators, and 2SIM access group will have access to Simulator 1 & 2 only.

Each medical student will be assessed monthly from month 0 to month 6 (7 visits) and each will have an hour session on simulator 1 & 2. 3SIM access group will have username and password access to simulator 3 via an internet enabled computer.

Project objective 2:

This will establish if a difference exists between eye tracking (eye movements) of novice surgeons (medical students) and expert surgeons (consultant orthopaedic shoulder surgeons). Results may allow the development of an eye movement training program which will enhance arthroscopic surgery training.

Hypotheses: during shoulder arthroscopy eye tracking of novice surgeons differs from expert surgeons

Methods: 20 medical students & 20 consultants shoulder surgeons will be recruited. During simulated arthroscopic shoulder procedures, eye tracking will be recorded.

Each medical student will be assessed monthly from month 0 to month 6 (7 visits). Consultant orthopaedic shoulder surgeons will be assessed once. Each visit will consist of an hour session on the virtual reality simulator.

Target audience:

Medical students who are able to give up 1 hour per month for 6 months to come to Bridgewater hospital to be assessed on the simulators. Those randomised into 3SIM access should practice on the simulator 3 as much as possible at home. All years are welcome, but priority will be given to senior years in the early cohorts. 25 students will be accepted every 6 months, so even if you are a junior year, put your name down and pre-register for the next cohort.

Demographic Questionnaire

Unique Identifier Number (UIN)		
Date of birth		
Sex (delete appropriate)	Male/female	
Participant year at medical school		
Eye sight correction	Left, Right, contact lenses	
Hand dominance (delete appropriate)	Left / Right / Ambidextrous	
Hobbies (please list)	1. 2. 3. 4. 5. 6. 7.	
Do you participate/play (please mark how many hours/week)	1. Computer games with joystick 2. Computer games with controller 3. Computer games keyboard/mouse 4. Computer games other 5. Knitting 6. Sewing 7. Needle work 8. Handheld consoles, e.g. Gameboy 9. Playing musical instruments & grade	
Do you participate/play computer games involving (please mark how many hours/week)	1. Role play (1^{st} person shooting) 2. Flight simulators 3. Car racing 4. Strategy 5. Other	
Do you participate in any activities that require manual dexterity or hand-eye coordination (give examples)		

Session Plan

50	10 mins	Intro, consent
00	5 mins	ASATs registration
05	15 mins	Watch videos of ASATs, VR, Alex
20	30 mins	Perform above
50	10 mins	Overtime

Raw Data

	ASATs parameters							
unique ID	timetaken	outtime	outnum	onbox	onwork	droptimes	distancetotal	delta_distance
1	25.531	0	0	60.0642	100	0	2480.02	1201.57
2	24.966	6.87335	2	66.8149	93.1267	0	3654.39	2447.4
3	13.231	0.128486	1	51.9084	99.8715	0	2846.26	1607.58
4	25.647	1.2984	2	57.0905	98.7016	0	4011.01	2768.84
5	21.012	0	0	56.6724	100	0	3101.46	1795.01
6	29.963	4.22855	5	57.7479	95.7715	0	4596.19	3310.83
7	26.681	0	0	64.1655	100	0	2484.48	1258.12
8	103.639	2.76344	4	58.8331	97.2366	3	9292.2	7995.52
9	33.75	0.58963	3	66.6341	99.4104	0	3800.93	2551.88
10	21.614	0	0	63.593	100	0	2497.69	1301.31
11	32.933	0	0	60.5745	100	2	3208.57	1931.99
12	36.95	0.722598	1	64.3085	99.2774	0	3211.79	1924.32
13	26.023	13.5265	6	43.5653	86.4735	1	6504.78	5257.54
14	15.683	0	0	58.1203	100	1	2592.41	1320.8
15	26.754	0	0	63.9904	100	1	2444.62	1178.18
16	36.93	6.06553	4	65.5294	93.9345	0	3754.61	2403.33
17	26.933	1.48517	1	62.2916	98.5148	1	3384.95	2050.31
18	53.17	3.87437	6	71.7698	96.1256	1	7575.33	6241.17
19	21.53	3.01904	3	64.784	96.981	0	4008.48	2792.73
20	33.898	8.35743	4	62.3282	91.6426	0	4206.72	2956.12
21	38.766	6.57793	6	66.1172	93.4221	1	5392.55	4123.7
22	36.283	1.19064	2	72.1963	98.8094	0	3428.81	2202
23	38.932	0.601048	1	66.0357	99.3989	1	3556.26	2310.26
24	20.91	0	0	66.7958	100	0	2315.75	1060.71
25	106.092	0.942578	2	66.8231	99.0574	7	5011.43	3756.37
26	22.779	4.46464	3	66.8159	95.5354	0	2977.5	1717.8
27	17.175	2.9345	2	63.6798	97.0655	0	2700.05	1397.97
28	17.381	0.414245	1	65.2437	99.5858	0	2888.68	1661.31
29	27.25	0	0	74.4771	100	1	2770.36	1474.28
30	52.367	1.99171	3	70.8729	98.0083	1	3472.69	2205.07
31	24.935	3.9984	3	56.8037	96.0016	0	3533.83	2320.02
32	34.19	0.400702	1	72.8693	99.5993	0	2921.3	1641.85
33	34.875	1.63728	2	56.7111	98.3627	1	4352.6	3132.94
34	27.388	0	0	72.1849	100	0	2836.09	1577.03
35	33.965	0	0	66.7216	100	0	2607.91	1309.28
36	44.531	1.93573	3	73.2478	98.0643	1	3094.8	1899.09
37	27.229	2.60384	2	63.5683	97.3962	0	3033.45	1728.89
38	17.872	2.70255	1	59.2771	97.2974	1	2584.6	1329.8
39	22.917	2.19924	1	75.2411	97.8008	0	2733.35	1450.08
40	17.7	0	0	59.5254	100	0	2385.28	1171.69
41	13.732	0	0	56.7288	100	0	2638.72	1389.04
42	28.181	0.532274	1	63.1241	99.4677	0	2679.97	1393.42
43	31.783	0	0	69.3861	100	0	2791.8	1589.98
44	17.782	0	0	66.6179	100	0	2337.21	1069.79
45	20.083	1.65812	1	58.6616	98.3419	0	2435.61	1247.9
46	35.999	10.1364	6	52.2931	89.8636	1	5491.12	4208.42
47	17.882	0	0	70.2326	100	0	2322.32	1044.57
48	28.917	0	0	70.7646	100	0	2702.96	1390.05
49	21.846	1.75318	1	67.9392	98.2468	0	2852.27	1477.35

	VR parameters						
unique ID	VR_pendulur	VR_pendulur	VR_pendulur	VR_pendulur	VR_pendulur	VR_visualise_	VR_visualise_
1	116.63	123.52	0	1304.23	43.16	211.64	1123.02
2	297.45	419.34	20.22	1305.64	30.67	220.29	692.47
3	45.76	38.59	0	207.89	3.96	347.27	1819.72
4	57.62	113.08	11.75	310.25	5.21	149.84	809.42
5	104.9	238.64	0.23	268.5	3.95	291.33	1290.03
6	104.06	323.97	1.67	355.37	3.81	192.63	1476.28
7	387.5	618.43	15.84	3618.1	21.23	455.06	2490.13
8	488.99	851.67	16.35	3299.39	19.3	736.02	3732.25
9	248.62	551.62	25.32	1350.61	3.83	330.99	2586.08
10	105.13	240.59	19.24	474.12	3.76	223.65	611.27
11	81.51	104.24	0	528.64	17.49	259.54	736.51
12	112.84	212.87	0.96	893.31	24.87	708.52	4332.91
13	98.93	393.67	9.74	581.03	18.15	696.29	3252.96
14	104.43	196.22	2.04	352.3	10.83	321.46	1025.18
15	88.12	129.66	0	357.62	3.83	526.33	1232.94
16	145.64	171.17	0	632.64	18.23	427.26	904.98
17	76.06	318.7	2.66	502.22	11.18	286.84	1892.37
18	373.63	787.16	2.17	2993.79	32.27	523.53	1543.2
19	56.02	112.98	0	295.96	2.21	389.63	1213.39
20	182.78	701.83	14.76	1222.26	8.61	327.48	1122.14
21	323.56	313.48	6.86	1559.9	19.49	470.49	2420.17
22	93.73	224.55	0	501.39	8.18	187.19	1033.37
23	50.45	74.78	0	165.34	3.83	261.04	905.85
24	175.78	580.31	16.38	1524.43	38.2	183.94	1046.44
25	327.84	1100.64	4.1	3065.81	9.72	532.89	2735.49
26	52.43	165.31	5.53	482.22	3.6	242.47	1116.32
27	126.7	608.39	1.78	777.02	13.13	287.23	1127.33
28	106.07	254.73	6.05	507.17	3.84	212.64	961.29
29	51.52	207.12	0.83	199.77	3.73	293.45	1237.54
30	65.06	215.89	0.15	324.11	15.63	263.7	1474.85
31	44.61	245.76	13.45	335.32	4.08	204.62	1805.92
32	146.65	321.27	19.45	653.94	4.47	170.88	644.07
33	116.27	141.32	0	455.22	9.8	175.15	473.09
34	113.38	174.75	0.32	655.39	4.75	267.4	948.79
35	151.79	369.14	3.27	863.45	34.14	227.61	1219.07
36	148.09	318.33	1.78	1057.24	26.96	240.24	1025.34
37	175.28	388.95	20.56	1085.58	12.65	474.83	1983.13
38	90.01	100.5	0	609.13	2.18	222.09	1127.73
39	96.33	184.38	1.25	785.69	7.98	168.91	1141.68
40	40.25	198.77	2.48	247.14	3.72	339.69	2483.1
41	43.86	118.39	1.7	93.2	0.14	186.16	694.84
42	100.6	146.4	9.86	510.64	3.84	245.21	1744.93
43	182.76	179.43	1.66	1082.83	21.7	672.79	2335.3
44	52.76	122.51	0	246.4	3.83	132.45	745.94
45	140.38	181.83	1.83	537.92	14.28	870.64	2815.2
46	167.07	170.55	0.99	1088.31	45.84	208.79	746.78
47	106.65	106.62	12.47	439.47	4.27	193.43	509.35
48	55.89	102.35	0	186.61	3.82	109.56	457.53
49	41.29	116.79	0	186.69	3.84	170.73	738.59

	VR parameters							
unique ID	VR_visualise_	VR_palpate_	VR_palpate_	VR_palpate_	VR_palapate	VR_palpate_	VR_OR_time	VR_OR_covd
1	26.95	288.93	1140.56	23.53	1294.82	4.29	220.94	1349.9
2	9.12	336.06	1265.97	15.69	1166.1	5.17	515.8	3421.28
3	22.03	238.87	877.94	6.84	939.72	3.92	175.73	1148.38
4	17.53	340.14	989.15	19.19	1267.8	11.58	166.96	964.64
5	25.24	292.74	1014.42	25.26	700.73	4.15	194.32	1337.24
6	37.64	384.91	2172.73	39.92	1124.52	27.79	195.47	2159.13
7	28.26	277.74	624.64	17.9	1430.49	5.08	270.8	2229.68
8	21.12	1248.8	4194.73	14.31	8412.79	43.31	559.64	3790.51
9	28.08	456.49	1898.47	25.04	2964.34	19.42	334.71	3151.26
10	8.93	274.02	367.76	25	683.14	3.86	441.52	1695.53
11	18.96	206.99	357.91	1.15	565.75	4.71	282.73	1222.83
12	16.23	311.46	914.81	27.81	2634.23	38.52	261.24	2137.08
13	23.25	282.51	974.82	6.47	1951.04	8.64	333.6	3459.59
14	13.3	148.86	377.5	0.24	370.99	0	750.92	4830.22
15	10.87	311.27	651.3	0.71	788.76	3.84	600.02	1860.23
16	6.13	425.21	920.64	10.15	1469.21	4.81	415.59	1641.6
17	25.11	148.41	595.81	8.97	422.73	3.9	227.73	1668.03
18	27.26	714.25	2315.7	20.25	2756.42	10.46	511.59	2601.7
19	17.59	320.01	743.39	7.73	1044.68	4.31	295.07	1732.12
20	20.77	948.98	3264.7	18.5	3033.51	9.45	511.82	2369.4
21	37.58	599.14	1869.95	24.95	2191.66	16.76	329.89	2021.49
22	27.5	323.85	1487.67	31.43	1504.06	15.97	147.7	1819.89
23	4.04	464.53	1457.14	25.85	1580.76	5.33	260.39	2204.65
24	13.5	250.08	982.12	35.21	629.12	3.84	179.02	899.39
25	34.01	408.13	1441.65	41.93	1861.05	12.5	284.79	1715.22
26	18.57	131.94	314.97	9.07	509.38	4.01	222.76	1899.8
27	14.47	240.71	1050.36	4.27	896.96	7.73	159.99	1200.06
28	24.21	272.04	1160.54	14.92	592.69	3.78	218.81	1682.85
29	37.44	354.17	1442.67	29.53	877.22	3.83	383.17	3085.86
30	20.19	273.5	864.25	8.83	1120.1	28.66	123.51	1419.35
31	15.52	202.44	1103.79	18.74	946.33	3.79	252.57	3571.18
32	26.48	404.29	1274.04	25.53	1721.77	27.03	117.13	889.95
33	1.98	224.17	562.65	4.32	570.19	3.83	289.65	1870.12
34	15.92	244.88	563.6	4.44	1061.55	51.5	238.08	1864.99
35	18.91	351.73	1000.2	30.4	1202.26	9.12	128.81	1145.55
36	21.73	268.92	1003.88	14.8	913.18	26.76	326.97	1834.21
37	19.45	322.3	971.12	13.08	1878.53	26.3	170.56	1612.51
38	21.17	153.1	459.43	23.21	715.62	6.01	134.9	1546.74
39	13.17	204.85	1060.63	18.09	1348.41	29.79	215.65	1952.7
40	25.08	279.74	1401.92	20.39	2210.45	42.28	176.95	1508.87
41	5.48	249.47	788.19	7.61	531.77	12.63	268.88	1519.92
42	20.56	303.05	866.5	33.75	1565.09	22.39	121.59	1277.44
43	26.44	642.1	1360.51	27.09	2253.61	32.64	391.14	1559.16
44	3.22	318.17	1187.5	11.05	2635.61	24.9	184.64	1548.74
45	34.71	534.59	1201.23	30.04	2105.02	33.57	264.85	1172.75
46	3.36	228.5	873.68	12.95	1037.43	6.15	176.67	1019.48
47	7.34	241.32	554.53	15.95	807.16	0	153.95	654.05
48	1.96	214.73	894.46	19.89	891.54	4.72	206.8	1637.5
49	21.51	209.31	621.61	10.3	595.09	3.9	231.16	1441.26